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*Canada. Conservation, Commission of.
"Committee on Minerals"*

COMMISSION OF CONSERVATION
CANADA



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[General publications]
Discovery

of

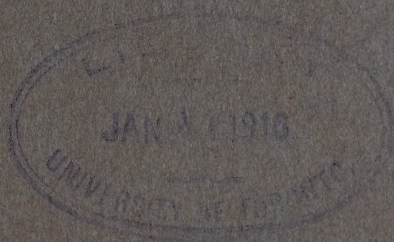
**Phosphate of Lime
in the
Rocky Mountains**

BY

FRANK D. ADAMS, D. Sc., F. R. S.


AND

W. J. DICK, M. Sc.



OTTAWA, 1915

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Canada. Conservation, Commission of-
" Committee on Minerals

Discovery of Phosphate of Lime
in the
Rocky Mountains

BY

FRANK D. ADAMS, D. Sc., F. R. S.

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OTTAWA:
THE OTTAWA PRINTING CO., LIMITED
1915

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111

TO FIELD MARSHAL HIS ROYAL HIGHNESS PRINCE ARTHUR WILLIAM
PATRICK ALBERT, DUKE OF CONNAUGHT AND OF STRATHEARN,
K.G., K.T., K.P., ETC., ETC., GOVERNOR-GENERAL OF CANADA

May it Please Your Royal Highness:

The undersigned has the honour to lay before Your Royal Highness a report on "The Discovery of Phosphate of Lime in the Rocky Mountains," by Frank D. Adams, D.Sc., F.R.S., and W. J. Dick, M. Sc.

Respectfully submitted

CLIFFORD SIFTON

Chairman, Commission of Conservation

OTTAWA, December 1st, 1915

OTTAWA, November 30th, 1915

Sir:

I have the honour to transmit herewith a report on "The Discovery of Phosphate of Lime in the Rocky Mountains," by Frank D. Adams, D.Sc., F.R.S., and W. J. Dick, M.Sc. The report contains an account of an investigation carried out by these two gentlemen on behalf of the Commission of Conservation, which has resulted in the discovery of deposits which are expected to provide a valuable source of fertilizing material for the grain fields of Western Canada.

I have the honour to be, Sir

Your obedient servant

JAMES WHITE

Assistant to Chairman

SIR CLIFFORD SIFTON, K.C.M.G.

Chairman

Commission of Conservation

CONTENTS

	PAGE
Reasons for Undertaking the Investigation—The Resulting Discovery of Phosphate in Alberta.....	1
Importance of Phosphatic Fertilizers.....	2
Phosphate Deposits of Montana, Idaho, Wyoming and Utah.....	4
Description of Phosphate Deposits near Maiden Rock, Montana.....	5
The Carboniferous Rocks of the Rocky Mountains in Canada.....	10
Discovery of Phosphate Rock in the Rocky Mountains Park at Banff.....	16
Suggestions for Prospectors in Search of Deposits of Phosphate Rock in the Rocky Mountains.....	20
Dominion Regulations Respecting Disposal of Phosphate Lands.....	23
Appendix—Phosphate Resources of the World.....	25
Leading References on Western Phosphate Deposits.....	31

VI

PLATES

	PAGE
I. View Looking down Forty-mile Creek from a Point One Mile North of Stoney Squaw Mountain.....	<i>Frontispiece</i>
II. View Showing the Geological Succession and the Position of the Phosphate Deposits near Maiden Rock, Montana.....	4
III. Sections Showing Geology of Phosphate Deposits near Maiden Rock, Montana.....	5
IV. Geological Sections.....	8
Section along Canadian Pacific Railway near Frank, Alberta	
Section along North Kootenay Pass	
Section in Vicinity of East Summit of North Kootenay Pass	
Section near Oil Creek, Eastern Slope of Clarke Range	
V. Outcrop of Phosphate Bed near Maiden Rock, Montana.....	12
VI. Phosphate Rock Found in Bed of Forty-mile Creek, Rocky Mountains Park, Banff, Alberta.....	14
VII. Stoney Squaw Mountain, Rocky Mountains Park, Banff, Alberta.....	17
VIII. Microphotographs of Phosphate Rock, Forty-mile Creek, Rocky Mountains Park, Banff, Alberta.....	20
IX. Microphotographs of Phosphate Rock, Forty-mile Creek, Rocky Mountains Park, Banff, Alberta.....	22

MAPS

I. Map of Phosphate Deposits, Alberta and United States.....	1
II. Elliston Phosphate Field, Montana.....	9
III. Map of Banff, Alberta.....	16

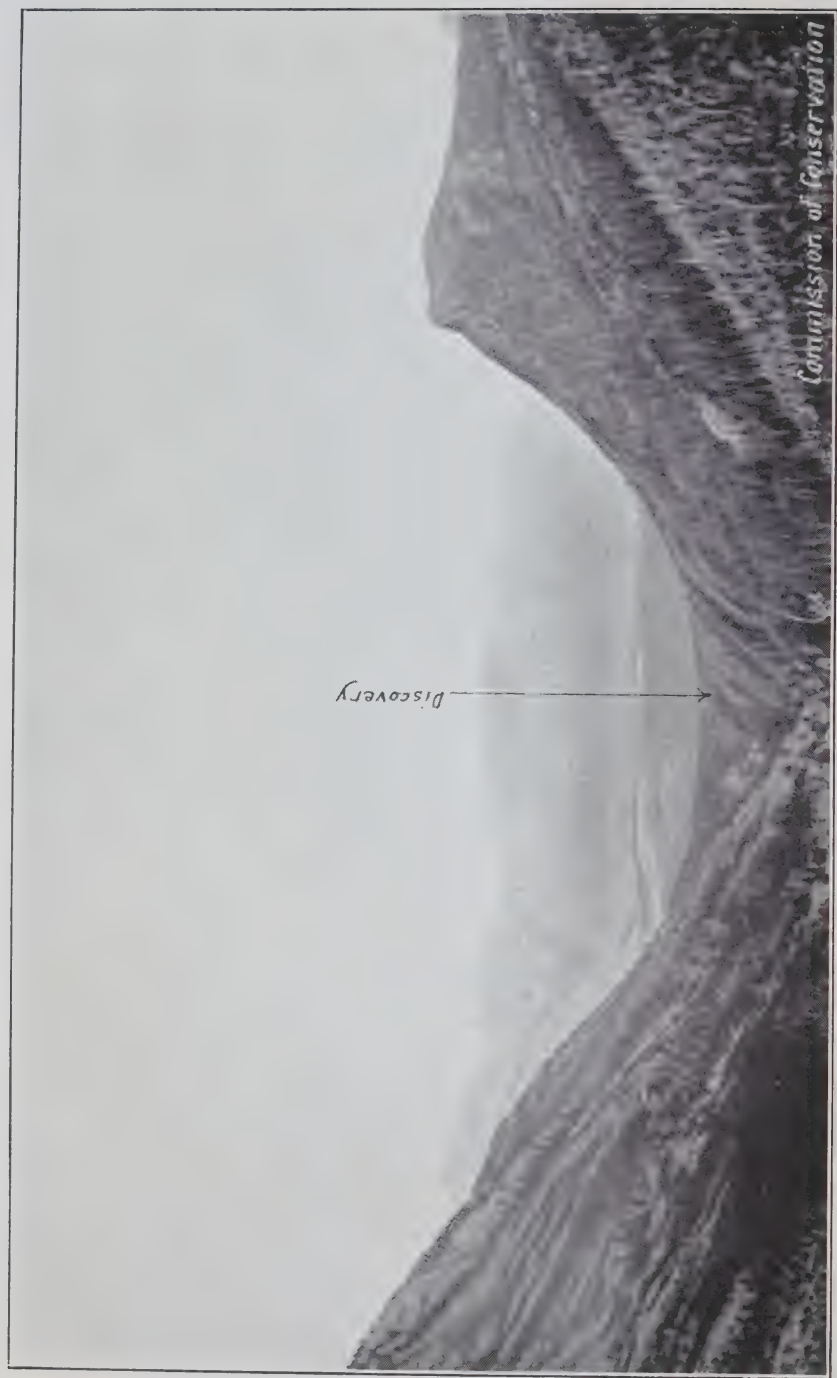


PLATE I—VIEW LOOKING DOWN FORTY-MILE CREEK FROM A POINT ONE MILE NORTH OF STONEY SQUAW MOUNTAIN
The phosphate rock was found in the bed of the creek at a point below the arrow.

116

114

112

110

108

Commission of Conservation Canada

1915

PHOSPHATE DEPOSITS ALBERTA AND UNITED STATES

Scale

0 20 40 60 80 100

Legend

Phosphate deposits

Distribution of Carboniferous
in Canadian Rockies

Note:— The Carboniferous extends northward
but its exact boundaries are unknown

52

52

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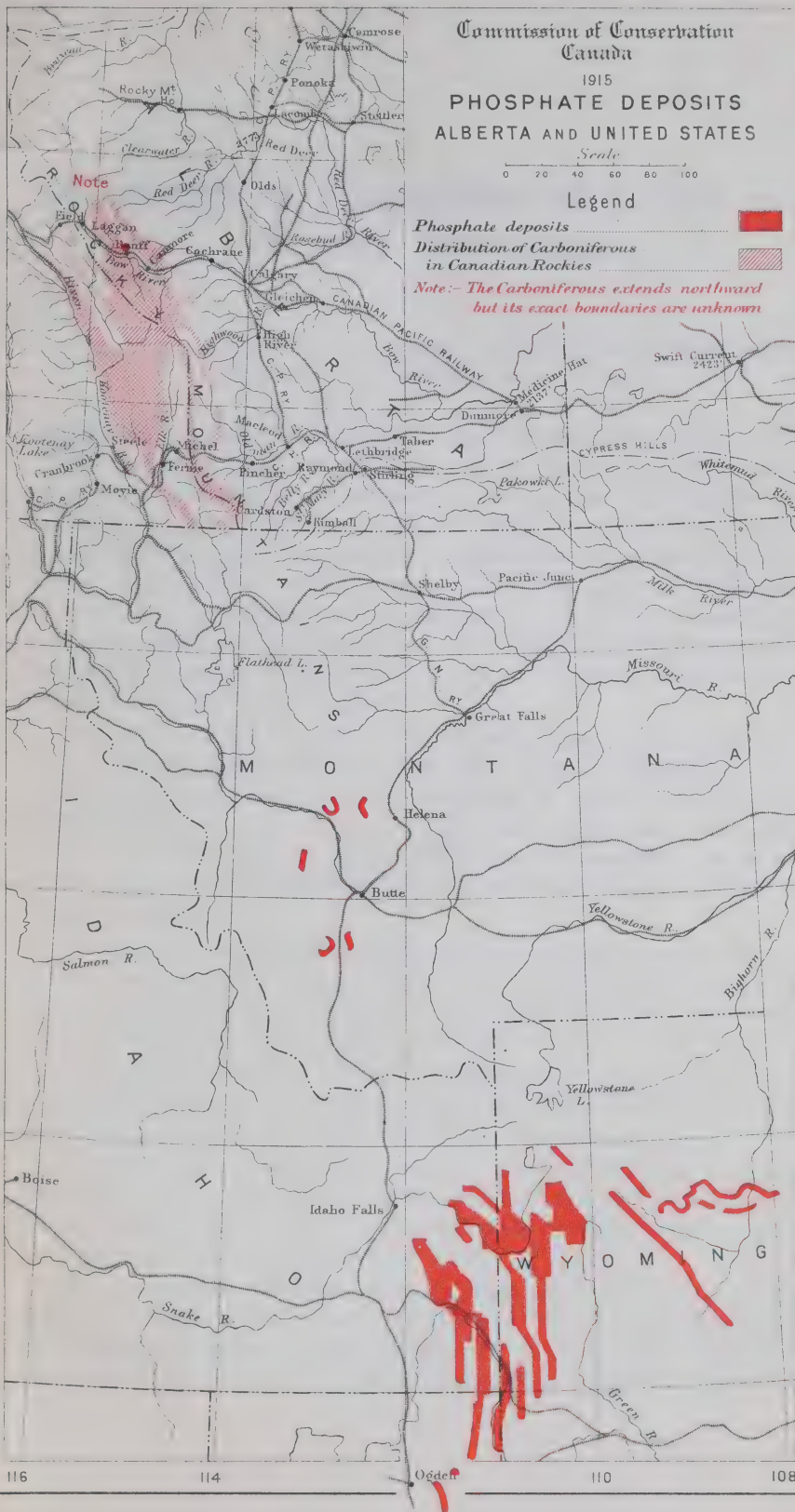
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44

44

42

42



Discovery of Phosphate of Lime in the Rocky Mountains

I.—REASONS FOR UNDERTAKING THE INVESTIGATION—THE RESULTING DISCOVERY OF PHOSPHATE IN ALBERTA

WITH the great development of agriculture in Western Canada there will arise in the not distant future an insistent and ever-increasing demand for fertilizers and manures. Among the constituents of such manures phosphoric acid is one of the most, if not the most, important. In all countries where agriculture is conducted on modern methods and where the maximum yield is obtained from the land, all sources of raw material for the manufacture of phosphates are eagerly sought for and exploited. In Canada, no deposits of mineral phosphates are known except the apatite deposits of the Ottawa district. These are of relatively small extent and are no longer worked.

In certain of the Western United States, however, especially in Utah, Idaho, Wyoming and Montana, great beds of mineral phosphate have been discovered recently and have been described in detail by officials of the United States Geological Survey. These discoveries have been hailed as of especial importance since they afford the raw materials on which the future development of agriculture in the western portion of the United States will be based.

It was even suggested at a conference of the Governors of the States, held in the year 1908, that, on account of the great value of phosphate deposits to the agriculture of that country, a law should be passed prohibiting the export of phosphates to foreign countries.

It seemed, therefore, to the Commission of Conservation of Canada that it was of the greatest importance that similar deposits of phosphate should be discovered within the Dominion of Canada.

These western phosphate deposits in the United States do not occur irregularly and at hap-hazard in the rocks of the earth's crust, but are found, wherever they occur, at a well-defined geological horizon, namely, near the top of the Carboniferous system.

It was evident, therefore, that the first step in the search for similar deposits in Canada was to ascertain where rocks of Upper Carboniferous age existed in Western Canada and whether the rocks of Carboniferous age occurring in the Western United States could be traced northward across

the border into Canada, and whether, if such were the case, the Upper Carboniferous rocks could anywhere be found in Canada with a development similar to that which they have in the phosphate district of the Western United States.

The Carboniferous rocks holding these western phosphate deposits in the United States would find their northern continuation, should such exist, in the Rocky mountains, in the provinces of British Columbia and Alberta.

The present report presents the results of a geological examination of the Canadian Rocky Mountains along three lines of section, which resulted in the discovery of phosphate in Canada—at a locality in the Rocky Mountains situated in the province of Alberta, 350 miles north of the nearest occurrence which is known in the United States.

A brief description is also given of the phosphate deposits of other countries, as well as directions to prospectors who desire to prosecute the search for phosphate beds.

II.—THE IMPORTANCE OF PHOSPHATIC FERTILIZERS

While a growing plant requires a number of chemical elements for its perfect development, three of these are especially necessary, namely nitrogen, potassium and phosphorus. These three substances are taken from the soil in such large amounts by growing crops, that, unless very special precautions are taken, the supply of these elements in the soil becomes greatly diminished and the fertility of the soil gradually declines until it can no longer be cultivated with profit. This is, briefly stated, the cause of the progressive exhaustion of the land which has had such far-reaching consequences in so many portions of the world.

Taking the wheat crop, merely as an index of yield, the result of continuous cropping in the United States without an adequate return to the soil of the constituents removed from it, is set forth in a recent Bulletin* of the United States Federal Department of Agriculture as follows:

“Wheat was successfully produced in central New York for something like 40 years. During the latter part of that period the yield began to decline, and at the end of another 20 years it was so low that exclusive wheat growing became unprofitable. Ohio, Indiana, Illinois and Iowa have each in turn repeated the history of New York. The soils of these states were productive in the beginning, and it required, 40, 50 or 60 years for the single crop system to materially reduce the yields.”

Now in the Eastern States are found in many regions abandoned farms with farm houses in every stage of decay. The average yield of wheat in

*See James J. Hill, *Highways of Progress*, p. 77.

New York state as recently as 1898 was 21.2 bushels per acre; in 1907 it was 17.3 bushels. In the same short time the average yield in Indiana fell from 15.6 to 14.4 bushels; in Minnesota from 15.8 to 13 bushels; in North Dakota from 14.4 to 10 bushels; in Oklahoma from 14.9 to 9 bushels.

The nitrogen which is taken from the soil by growing crops may be returned to it by ploughing in crops of clover, which have the power of fixing the nitrogen of the air and conveying it to the soil in the form of certain nitrogen compounds. It can also be supplied directly to the soil in the form of ammonium sulphate, which is now obtained in large quantities as a by-product in the coking of coal, or in the form of certain other nitrogen compounds manufactured from the air by certain electrical processes.

Potash, which is of equal importance, is usually present in soils in relatively larger amount, although in all processes of intensive farming by which especially large yields are obtained from the soil, this substance is returned to the soil through the medium of some kind of fertilizer.

Phosphorus, in the form of some phosphate, is of very especial importance, and if no steps are taken to restore to the soil the supplies of this substance abstracted and removed by the crops, the soil becomes gradually impoverished and will finally cease to produce a profitable yield.

Dr. C. G. Hopkins, in his book on *Soil Fertility and Permanent Agriculture*, page 183, states that:

"Phosphorus is the only element which must be purchased and returned to the most common soils of the United States. *Phosphorus is the key to permanent agriculture on these lands.* To maintain or increase the amount of phosphorus in the soil makes possible the growth of clover (or other legumes) and the consequent addition of nitrogen from the inexhaustible supply in the air; and, with the addition of decaying organic matter in the residues of clover and other crops and in manure made in large part from clover hay and pasture and from the larger crops of corn and other grains which clover helps to produce, comes the possibility of liberating from the immense supplies in the soil sufficient potassium, magnesium and other essential abundant elements, supplemented by the amounts returned in manure and crop residues, for the production of large crops at least for thousands of years; whereas, if the supply of phosphorus in the soil is steadily decreased in the future, in accordance with the past and present most common farm practice, then poverty is the only future for the people who till the common agricultural lands of the United States.

"And this does not refer to the far distant future only, for the turning point is already past on most farms in our older states and on many farms in the corn belt; and lands that have passed their prime with sixty years of cultivation will decrease rapidly in productive power and value during another sixty years of similar exhaustive farm practice."

In 1914 the wheat production of Canada amounted to 158,223,000 bushels—the average yield per acre being about 15.37 bushels. Allowing

two pounds of straw as removed for every pound of grain, and taking the average analysis of wheat and straw, the following amounts of plant-food were removed from the soil during that year by the wheat crop alone.

Nitrogen	300,000,000 pounds.
Phosphoric acid	95,000,000 "
Potash	137,000,000 "

While the virgin soils of the western provinces of Canada and especially the very deep rich soils of Manitoba, continue for years—and in some cases for many years—to produce heavy yields even under continuous cropping, they are by this process being gradually depleted, and as the supplies of plant food in them become gradually reduced, the signs of exhaustion will be manifested in decreasing returns. As a matter of fact, this depletion is already manifesting itself as shown by an investigation recently carried out by the Commission of Conservation.*

In order to maintain the fertility of the soil, these valuable constituents taken from the soil must be returned to it. Of these, as has been mentioned, the most important is phosphoric acid.

In 1913 there were 16,726,400 acres of land under cultivation in the three Prairie Provinces and the depletion per acre annually may be taken as equivalent to the phosphoric acid contained in 60 pounds of high-grade phosphate rock. At this rate 501,800 tons of high-grade phosphate rock would be required each year simply to offset the depletion of the land already under cultivation in Manitoba, Saskatchewan and Alberta.

III.—PHOSPHATE DEPOSITS OF MONTANA, IDAHO, WYOMING AND UTAH

Phosphates were first discovered at certain localities in north-eastern Utah and south-eastern Idaho, in the district where the states of Utah, Idaho and Wyoming come together. From thence the deposits were traced to the north as far as the vicinity of Helena, Montana, and south-east and west in the states of Idaho, Utah and Wyoming. They are now known to occur in an area in Montana, south-eastern Idaho, north-eastern Utah and south-western Wyoming, having an extent of about 420 miles north and south and about 220 miles in an east and west direction. (Map No. 1 shows their distribution.)

The phosphate rock occurs in the form of well-defined beds interstratified with rocks of Upper Carboniferous age, although by some observers they have been classed as Permian. These constitute what is termed the Phosphoria formation, a series of shales, sandstones and limestones aggregating about 100 feet in thickness and containing one or more beds of phosphate rock ranging in thickness from a few inches to ten feet.

*See *Fifth Annual Report*, Commission of Conservation, p. 168.

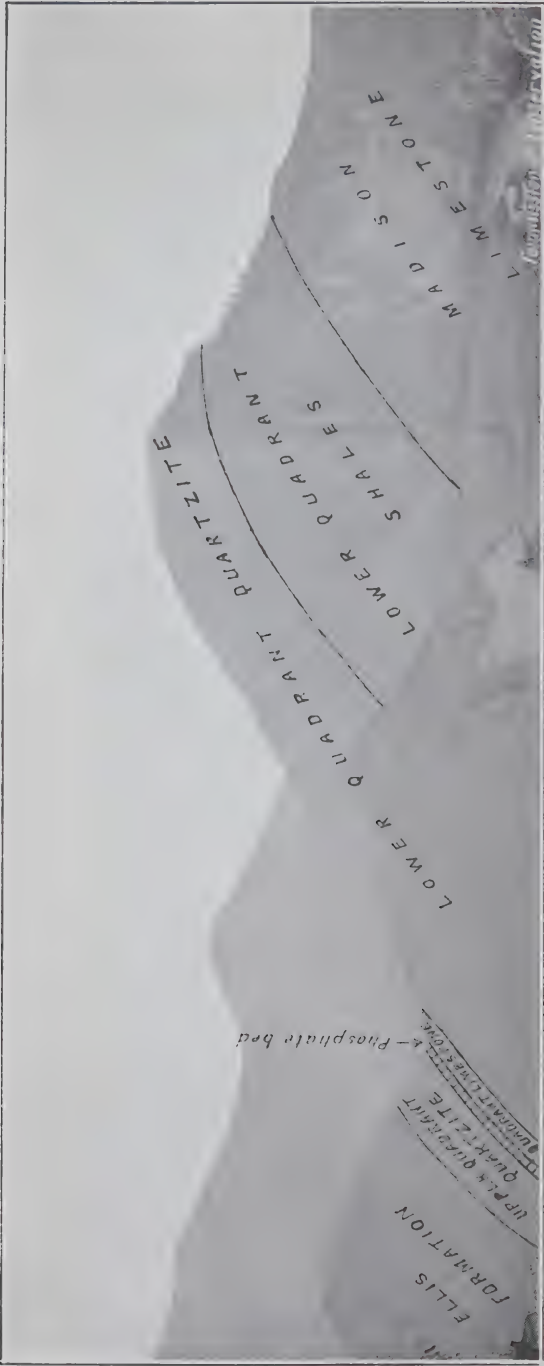
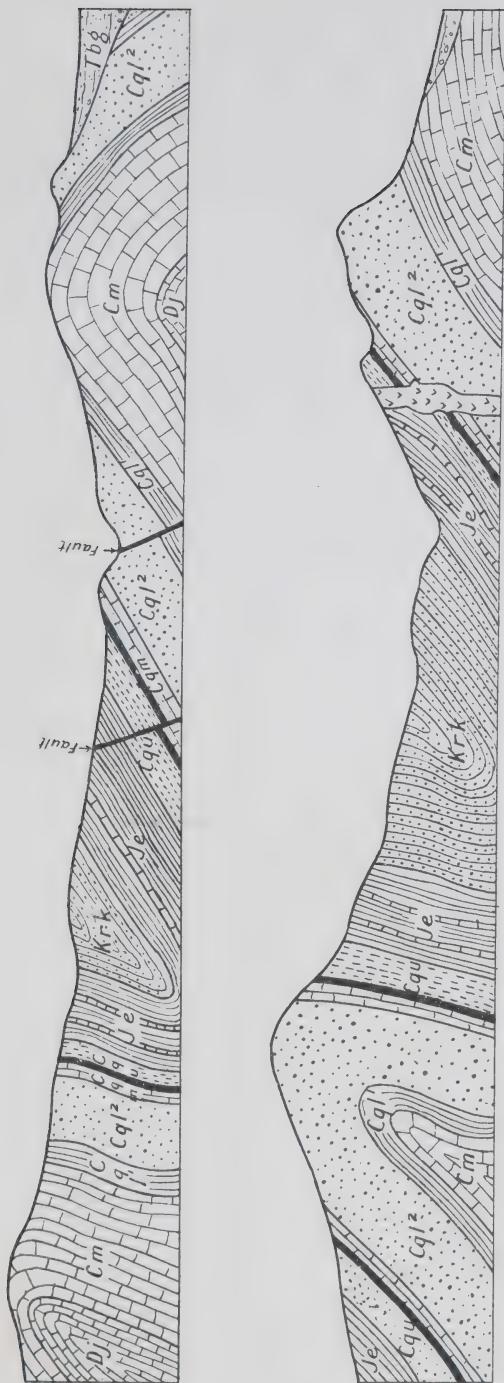


PLATE II—VIEW SHOWING THE GEOLOGICAL SUCCESSION AND THE POSITION OF THE PHOSPHATE DEPOSIT NEAR MAIDEN ROCK, MONTANA



SECTIONS SHOWING GEOLOGY OF PHOSPHATE DEPOSITS NEAR MAIDEN ROCK, MONTANA

After P. Billingsley and M. H. Gidel

2000 feet = 1 inch

LEGEND

Quadrant upper quartzite

Phosphate bed

Quadrant middle limestone

Quadrant lower quartzite

Quadrant lower shale

CRETACEOUS Kootenay S.S.

JURASSIC *Ellis formation* Je

Ellis formation

UPPER
CARBONIFEROUS
(PENNSYLVANIAN)

UPPER
CARBONIFEROUS
(PENNSYLVANIAN)

LOWER
CARBONIFEROUS
(MISSISSIPPIAN)

Madison Limestone

Usually one, and sometimes two, of these beds in a given section is workable and probably some of the others can eventually be mined.

The rocks of this Phosphoria series weather away readily under the action of the atmospheric forces and its outcrop is, therefore, inconspicuous, but the strata above and below it are usually resistant and stand out in ledges which can easily be traced. The lime phosphate in the beds varies from a small unworkable content to 80 per cent.

On pages 6 and 7 there is presented a table showing, in comparative form, the geological sections in Montana and Idaho.

This great phosphate field having been discovered only in very recent years and in most places lacking transportation facilities, has as yet been worked but to a very limited extent. It, however, embraces the largest known area of phosphate beds in the world and at some future time will probably supply a large part of the world's production of commercial fertilizers. The development of intensive farming as a result of the reclamation of the arid lands of the West will afford an ever-increasing market in the United States.

IV.—DESCRIPTION OF PHOSPHATE DEPOSITS NEAR MAIDEN ROCK, MONTANA*

These deposits are of especial interest in connection with possible occurrences in Canada in that they represent those phosphate deposits in the United States which lie nearest to the Canadian border. There is, therefore, a probability that their characters, conditions and geological relations are those which would be found in deposits occurring in the Dominion of Canada. This region was, therefore, examined by the writers in company with Dr. Lindforth of the geological staff of the Anaconda Copper and Mining Co., of Butte City, Montana, which company has already done some preliminary work in opening up the deposits in question.

Maiden Rock is a station on the Oregon Short Line railway, about 25 miles south of Butte City, Montana.

The following formations are exposed in this locality:

CRETACEOUS

Kootenai formation

JURASSIC

Ellis formation

CARBONIFEROUS

(a) PENNSYLVANIAN

Upper Quadrant quartzite

Phosphate bed

Middle Quadrant limestone

*Stone, R. W., and Bonnie, C. A., *The Elliston Phosphate Field, Montana*; U.S. Geol. Survey, Bull. 580N.

TABLE SHOWING GEOLOGICAL SECTIONS IN THE PHOSPHATE AREAS
NEAR FRANK AND

ELLISTON, MONTANA	MELROSE, MONTANA	ALBERTA (near Frank)
<p>MESOZOIC FORMATIONS {</p> <p>Buff-weathering sandstone and shale and arenaceous limestone</p> <p>Thick bedded quartzose sandstone, containing black chert pebbles</p> <p>Black chert (is common immediately over phosphate)</p> <p>PERMIAN—</p> <p>Phosphoria formation</p> <p>Sandstone and shale, soft greenish brown 75 ft.</p> <p>Phosphate rock, shown by bluish-white float 5 ft.</p> <p>PENNSYLVANIAN—</p> <p>Quadrant (?)—</p> <p>Quartzite, white, massive, ledge maker . . 50 ft.</p> <p>Quartzite, gray, pink and white, interstratified with shale 210 ft.</p> <p>Sandstone & shale 200 ft.</p> <p>Quartzite, gray and pink variegated . . . 30 ft.</p> <p>Shale, sandy, soft, reddish in places . 150 ft.</p> <p>MISSISSIPPIAN—</p> <p>Madison limestone, blue, weathers white 1,000 ft. +</p>	<p>CRETACEOUS—</p> <p>Shale, black fissile (probably Colorado, Upper Cretaceous)</p> <p>Sandstone, fine grained brown and rusty weathered (base of Colorado) 10 ft.</p> <p>Shale in part vari-coloured . 200 ft.</p> <p>Kootenai (near top) limestone, dark blue, containing gastropods 10 ft.</p> <p>Sandstone, dark green and buff, also vari-coloured shales (maroon, green, yellow, brown, etc.) including thin beds of blue limestone 600 ft.</p> <p>Kootenai formation (base of)</p> <p>Quartzite, or sandstone and massive ledges of coarse-pebble conglomerate . . . 100 ft.</p> <p>TRIASSIC (?) JURASSIC (?)—</p> <p>Shale, with some limestone, showing decided green and brown in upper part . . . 400 ft.</p> <p>PENNSYLVANIAN—</p> <p>Chert (and quartzite) massive; yellow stained, brecciated 100 ft.</p> <p>Phosphate bed 5 ft.</p> <p>Limestone, blue, sandy, with black chert in nodules and layers 130 ft.</p> <p>Quadrant formation—</p> <p>Quartzite, very massive, white vitreous 400 ft.</p> <p>Sandstone, quartzite and sandy shale including dark red and purple bands 300 ft.</p> <p>MISSISSIPPIAN—</p> <p>Madison limestone, massive blue-weathering ledges. 1,000 ft.</p>	<p>CRETACEOUS—</p> <p>Allison Creek</p> <p>Benton</p> <p>Crowsnest volcanics</p> <p>Dakota</p> <p>Kootenay 650 ft.</p> <p>JURASSIC—</p> <p>Fernie shale . 750 ft.</p> <p>DEVONO-CARBONIFEROUS {</p> <p>Massive light gray limestone 4,000 ft. +</p>

OF MONTANA AND IDAHO, AS COMPARED WITH GEOLOGICAL SECTIONS
NEAR BANKHEAD, ALBERTA.

ALBERTA (near Bankhead)	GENERAL SECTION OF PHOSPHATE AREA IN IDAHO
CRETACEOUS— Upper ribboned sand- stone..... 550 ft. +	CRETACEOUS (?)— Agglomerate (of fault origin [?]) composed of frag- ments and masses of volcanic ash (whitetuff) and triassic and carboniferous rocks.
Kootenay coal measures 2,800 ft. +	
Lower ribboned sand- stone..... 1,000 ft. +	TRIASSIC or CARBONIFEROUS (Including the Middle or Lower Triassic of Hyatt and Smith)— Ankareh shale, consists essentially of red shale and mottled red and greenish clay and shales, with some sandstone and some limestone. . . 770 ft. Thaynes limestone, the main body of the formation consists of dark blue limestone in many places fossiliferous, weathering to a brown muddy colour, also including sandy and calcareous shale..... 2,000 ft. Woodside limestone, thin bedded platy limestone, somewhat shaly and sandy. . . 1,000 ft.
JURASSIC— Ferne shale..... 1,500 ft. +	
PERMIAN— Upper Banff shale... 1,400 ft. + (dark brown arenaceous shale)	
PENNSYLVANIAN— Rocky Mountain quart- zite..... 800 ft. + (white to gray quartzite and arenaceous silicious lime- stone.) Upper Banff limestone 2,300 ft. + (thick bedded dark gray lime- stone with numerous thin cherty layers and underlain by thin bedded limestone and shale, weathering gray.)	PENNSYLVANIAN— Park City formation..... 600-800 ft. (a) One or more massive strata of cherty limestone or chert, prominent as a ledge maker, grading in part to a purplish chert or a flinty shale. (b) Rock phosphate, phosphatic shale and minor limestone bands. (c) Limestone, massive, white to light bluish, granular, weathering with projecting fossil frag- ments, usually with bluish chert bands and in some localities black chert in rounded nodules in the lower portion. Weber (?) formation (white sandstone and quartzite, calcareous sandstones and light coloured limestones, with variable amounts of interbedded quartzite)..... 1,000 ft. Morgan (?) formation (light coloured lime- stone with interbedded sandstone)..... 500 ft.
MISSISSIPPIAN— Lower Banff shale..... 1,200 ft. (black to dark gray shale, argillaceous and calcareous weathering light brown.) Lower Banff limestone. 1,500 ft. (Thick bedded gray limestone with numerous dolomitic seg- regations.)	UPPER MISSISSIPPIAN— Bluish-gray limestone with spherical nodules of black chert; gray sandy limestone streaked with calcite and speckled with siderite; locally marked by corals and crinoid stems..... 1,200 ft. LOWER MISSISSIPPIAN— Madison limestone, massive blue gray limestone, a thick formation making high mountainous country where brought to the surface in mass.

Lower Quadrant limestone
Lower Quadrant shale and sandstone

(b) MISSISSIPPIAN
Madison limestone

DESCRIPTION OF FORMATIONS

CRETACEOUS

Kootenai Formation—This formation probably represents the base of the Kootenai and is composed of quartzite, or sandstone, with massive ledges of coarse-pebble conglomerate. The sandstone is evenly bedded, greenish and brownish in colour and composed of fine sandy material.

JURASSIC

Ellis Formation—The Ellis formation, which is Triassic or Jurassic in age has a thickness of about 900 feet and lies conformably on the Upper Quadrant quartzite. It is composed of shale, green, brown or purple in colour, with some limestone.

CARBONIFEROUS—(a) Pennsylvanian

Quadrant Formation—The Quadrant formation is composed of an upper and more massive portion consisting chiefly of quartzite, 200 feet in thickness, forming prominent outcrops of hard ledges, including some shaly layers.

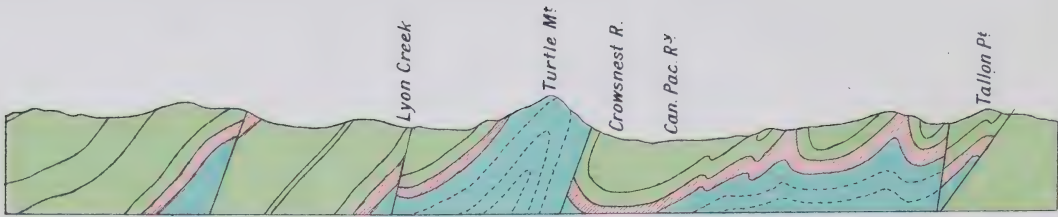
This is underlain by the Middle limestone, about 180 feet in thickness. This limestone contains much black chert. The phosphate bed, having an average thickness of about four feet, occurs between the Middle limestone and Upper quartzite, and on account of its softness and its position between two more resistant formations, the outcrop usually occupies a depression.

The Middle limestone is underlain by a massive white quartzite, 750 feet in thickness, which in turn is underlain by about 300 feet of sandstone and sandy shale including dark red and purplish bands.

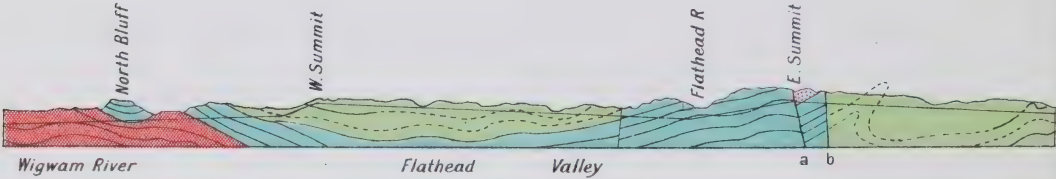
(b) Mississippian

Madison Limestone—The Madison limestone consists of heavy massive beds of light-coloured limestone, which, resisting erosion, give rise to strongly marked rugged topographic features. Its thickness at Maiden Rock is about 1,500 feet.

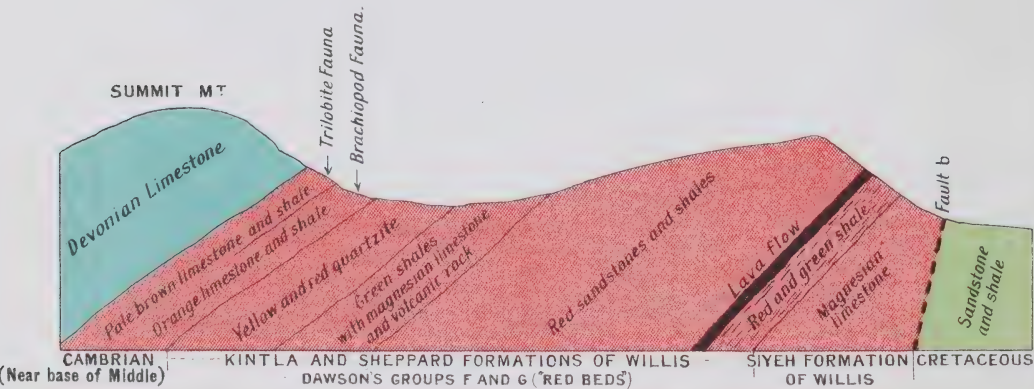
The fauna of this formation corresponds to that of the basal portion of the "Wasatch Limestone" of the Wasatch mountains of Utah.



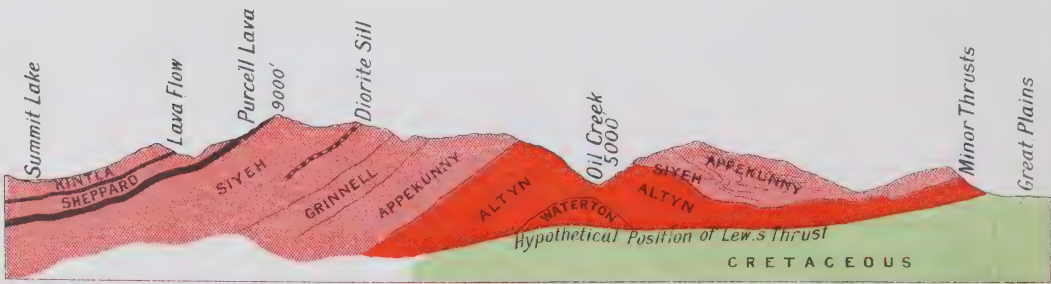
Section along Canadian Pacific Railway near Frank, Alberta. Scale, 2 miles to 1 inch
(After W. W. Leach)



Section along North Kootenay Pass. Scale, 6 miles to 1 inch
(After Geo. M. Dawson)



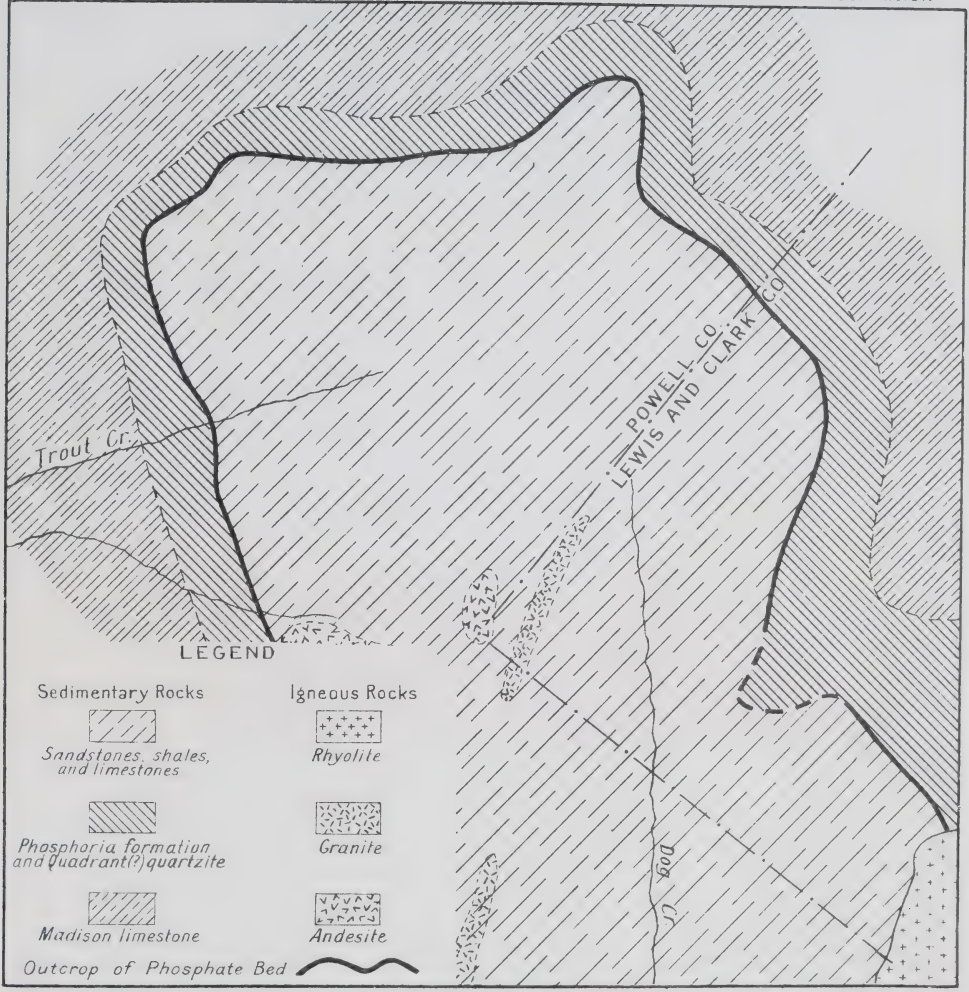
Section in vicinity of East Summit of North Kootenay Pass. Scale, 1300 feet to 1 inch
(By Adams and Dick)



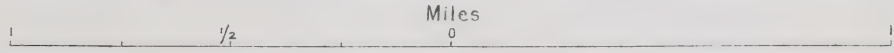
Section near Oil Creek, eastern slope of Clarke Range. Scale, 1.8 miles to 1 inch
(After R. A. Daly)

LEGEND

CRETACEOUS.....	JURASSIC.....	CAMBRIAN.....
TRIASSIC.....	CARBONIFEROUS AND DEVONIAN.....	PRE-CAMBRIAN.....



ELLISTON PHOSPHATE FIELD, MONTANA



Plates II, III and V illustrate the structure of this district and show the position of the phosphate bed in the Maiden Rock district.

In many districts the massive blue Madison limestone, which is about 1,000 feet thick and conspicuously exposed, is a guide to the phosphate bed which lies from 400 to 700 feet above it, with sandy shale and quartzite between.

DESCRIPTION OF THE PHOSPHATE ROCK

The fresh phosphate rock is dark gray to black in colour, and on the weathered surface is characterized by a bluish white tinge known as phosphate bloom.

It is usually rather soft and somewhat earthy in appearance, but in some places is hard, black and compact, having the appearance of a fine-grained basalt.

It has a distinctly higher specific gravity than quartzite, chert, shale and other rocks with which it is usually associated, the rich varieties having a specific gravity of about 2.9, as compared with 2.65 for quartz. A fragment thus is noticeably heavier than these rocks when taken in the hand.

Moreover, it frequently gives off a faint fetid odour when broken by a hammer. This, however, is not very distinct in all cases.

One of the most distinctive characters of the phosphate rock is an oölitic structure, which is almost invariably present. The rock showing this structure, when carefully examined under the lens, appears to be made up of minute spheres, like homœopathic pills, which usually range in size from .01 to .1 inch in diameter. These are tightly cemented together and in thin sections under the microscope usually show a concentric and sometimes a radial structure. This structure is excellently seen in the Maiden Rock phosphate.

On analysis the phosphate rock is found to contain from 20 to 35 per cent of phosphoric acid, equivalent to from 43.7 to 76.2 per cent of tricalcium phosphate.

The phosphate rock occurring in the form of a bed has, of course, the same continuity and regularity as is possessed by a coal seam or any other bedded deposit. Its outcrop is well illustrated in Map II, which shows the large area beneath which the phosphate bed extends.

It is estimated that the Elliston field, to which the Maiden Rock occurrence belongs, contains over 86,000,000 tons of phosphate rock.

The phosphate deposit at Maiden Rock has been opened up by a crosscut tunnel driven near the valley level and some 100 tons of the rock have recently been sent to the plant of the Anaconda Copper and Mining Co. at Anaconda for experimental treatment.

V.—THE CARBONIFEROUS ROCKS OF THE ROCKY MOUNTAINS IN CANADA

Since, as has been stated, the phosphate deposits of the western portion of the United States are found at a definite geological horizon which is situated near the top of the Carboniferous system, it was evident that in Canada the search for these rocks should be confined to areas underlain by rocks of Carboniferous age and in which the Carboniferous had a development similar to that found in the Western States, and that within this system the search might be restricted to its upper portion.

In this western portion of the United States, no phosphate deposits have been found north of Helena, Montana, for no rocks of Carboniferous age occur between this place and the Canadian boundary, which is 200 miles distant. The intervening area is underlain chiefly by rocks of Pre-Cambrian age which are carried over the newer strata by the great Lewis overthrust fault. About the boundary line, however, the Carboniferous re-appears and its distribution in Canada is shown in the map "Phosphate Deposits, Alberta and United States." As will be noted, the rocks of this age are confined to the Rocky mountains.

Three lines of section across the Rocky mountains were accordingly selected and carefully examined with a view to ascertaining whether along any of these lines the geological conditions were favourable for the discovery of phosphate.

These three lines were:

- (a) The North Kootenay pass.
- (b) The Crowsnest line of the Canadian Pacific railway—in Turtle Mountain district.
- (c) The main line of the Canadian Pacific railway east of the summit in the Rocky Mountains park at Banff, Alberta.

(a) *The North Kootenay Pass:* This crosses the Rocky mountains about 20 miles north of the International Boundary line. A geological reconnaissance was made along the line of this Pass by Dr. G. M. Dawson, when geologist to the Boundary Commission appointed to survey the 49th parallel in 1886.

In the geological section accompanying Dr. Dawson's report, and which is reproduced on Plate IV, the Carboniferous and Devonian rocks are shown as occurring in the district about the East Summit of the North Kootenay pass and, dipping to the west beneath the Cretaceous rocks of the Flathead valley, as re-appearing near the West Summit of the pass where they overlie the Cambrian. Immediately to the east of this East Summit of the pass, Dawson shows a block of these Devonian-Carboniferous strata lying between two faults (*a* and *b* in Plate IV) and overlain by a series of "Red Beds" which he supposed to be of Permian or Triassic age

on account of its resemblance to a series of this age found by Meek in Utah. One of these faults brings the supposed Devono-Carboniferous rocks against the Cretaceous on the east, while the other brings these rocks with the overlying "Red Beds" against the main body of the Devono-Carboniferous series on the west. If Dawson's interpretation of the age of the "Red Beds" is correct, the phosphate horizon should be in this Carboniferous series between the faults and a short distance below the base of the beds in question.

Bailey Willis examined the Lewis and Livingston ranges in Montana, immediately to the south of the Boundary line in this district, in the year 1902, and as the result of a more detailed study of the succession than was possible in Dawson's case, arrived at the conclusion that these "Red Beds" (his Kintla formation) are much older than Dawson supposed, being probably referable to the Pre-Cambrian ("Algonkian"), while the underlying limestone formations are not Carboniferous but still older members of the Pre-Cambrian. Daly* considers the "Red Beds" to be "Pre-Devonian" in age. His structural section of the Clarke range is shown on Plate IV.

On page 12 is a comparative table of the stratigraphical succession as interpreted by Dawson and Willis† respectively.

**North American Cordillera, Forty-ninth Parallel*, Geol. Survey of Canada, Memoir No. 38, Part I, 1912, p. 83.

†See Willis—*Lewis and Livingston Ranges, Montana*—Bull. Geol. Soc. Am, 1902, p. 318.

DAWSON		WILLIS	
CRETACEOUS		CRETACEOUS	
		CARBONIFEROUS	
Probably Triassic or Permo-Triassic	Series H. Fawn-coloured flaggy beds seen only at a distance, but probably composed of magnesian sandstones and limestones. 100 feet.	Kintla Argillite	"Algonkian"
	Series G. Beds characterized by a predominant red colour and chiefly red sandstone, but including some thin grayish beds, and magnesian sandstones, the whole generally thin-bedded, though sometimes rather massive. Ripple marks, etc. Weathers to a steep rocky talus where exposed in the mountain sides, and passes gradually down into the next series. 300 feet.		
	Series F. Fawn-coloured flaggy beds of magnesian sandstone and limestone. Some red sandstones occur throughout, but are especially abundant toward the top. Apparently a continuation upward of the limestone D, and only separated from it by the trap over-flow. 200 feet.		
Series E. Amygdaloidal trap; dark coloured and hard. 50 to 100 feet.	Shepherd Quartzite		
Carboniferous or Devonian	Series D. Compact bluish limestone, somewhat magnesian, and weathering brownish. This forms some of the boldest crags and peaks of the mountains, and apparently rests unconformably on Series C. 1,000 feet.	Siyeh limestone	
	Series C. Sandstones, quartzites, and slaty rocks, of various tints but chiefly reddish and greenish gray; the individual beds seldom of great thickness, and the colour and texture of approximate beds rapidly alternating. In this series occurs a band of bright red rocks, of inconstant thickness; also two or more zones of coarse magnesian grit. 2,000 feet or more.	Grinnell and Appekunny formations	
Cambrian	Series B. Limestone, pale gray, cherty, and highly magnesian; hard, much altered, and weathering white. It includes at least one band of coarse, magnesian grit, like that found in the last series, which weathers brown. 200 feet.	Uppermost beds of Altyn limestone	
	Series A. Impure dolomite and fine dolomitic quartzites; dark purplish and gray; but weathering bright brown of various shades. 700 feet or more.	Altyn limestone upper part	



PLATE V—OUTCROP OF PHOSPHATE BED NEAR MAIDEN ROCK, MONTANA

Dawson states that "the division between Series F and G and that between G and H are probably not of great importance. No unconformity obtains and very similar conditions of deposition appear to have prevailed throughout. . . . The divisions are, therefore, recognised as a matter of convenience only and are founded on the different colours of the formations as they appear on the mountain sides."

While examining the district last August, a magnificent section through the upper half of this succession was found on the long bare ridge running parallel to the North Kootenay pass and about three miles north of the East Summit. Here in a series of brownish yellow and orange limestones, which occupy the position of Dawson's Series H, an abundant trilobite and brachiopod fauna was discovered. The specimens collected have been examined by Dr. Kindle and Mr. Burling of the Geological Survey of Canada. Among them are representatives of the genera *Agraulos*, *Albertella* and *Ptychoparia*, which definitely fix the horizon as belonging to the lower part of the Middle Cambrian. The underlying "Red Beds" with the limestones underlying them and supposed by Dawson to be Carboniferous, are Lower Cambrian or Pre-Cambrian.*

A large number of fossils were also obtained from the great series of limestones forming Summit mountain, which rises from the East Summit of the North Kootenay pass. These were collected at various horizons from the base to the summit of the mountain and have been examined by Dr. Kindle. They prove that the whole excellently stratified succession of limestones which constitutes Summit mountain is of Upper Devonian age. No evidence of the existence of Dawson's fault (a) was found and the succession west of fault (b) is apparently continuous and conformable. This succession is shown on Plate IV.

The Cambrian limestones holding the fauna of Trilobites and Brachiopods are not exposed on the line of the North Kootenay pass itself, although they actually underlie the East Summit of the pass. They are here concealed by the heavy mantle of talus formed of material which has fallen from the slopes of Summit mountain.

With the recognition of the fact that the "Red Beds" are not Permian but Lower Cambrian or Pre-Cambrian in age, it is evident that the underlying limestones of the Siyeh formation are not Carboniferous as Dawson supposed, but that they also are Lower Cambrian or Pre-Cambrian.

The Carboniferous does not, therefore, appear in this section and the phosphate horizon is not represented in this area.

Limestones of Carboniferous age (Mississippian) have, however, been recognized on the west side of the Flathead valley. They occur overlying similar limestones of Devonian age, the two though not distinguishable in the field, being recognizable by palaeontological evidence.

*Schofield, S. J. (loc. cit. p. 52) shows there is reason to believe that the Siyeh formation in the Cranbrook area is Pre-Cambrian.

This Carboniferous limestone constitutes what is known as the Wardner formation.* These limestone formations are dropped down by a great fault so that they lie in contact with series of much older date, the fault in question having, according to Daly†, a displacement of between 15,000 and 20,000 feet. Dowling†† refers to "the downtilted block of Carboniferous limestone with reddish tinted upper beds which may be Permian or Triassic."

The geological structure of this district has not, however, as yet been worked out. It would, therefore, be advisable to examine this section on the North Kootenay pass to the west of the Flathead river for the purpose of ascertaining whether any Upper Carboniferous beds can be found overlying the Mississippian limestones. If Dowling's conjecture that the reddish beds to which he refers are of Permian age, the strata at their base would form a probable horizon for the occurrence of phosphate of lime. They may, however, be the same beds as those referred to by Dawson.

(b) *The Crowsnest Pass at Turtle Mountain, Alberta*: A great development of Devono-Carboniferous rocks is here exposed on the line of the Canadian Pacific railway. These rocks are bounded on either side by the Fernie shales, which are of Jurassic age. To the west, according to Leach, these shales overlie the Devono-Carboniferous series in regular succession, thus showing that the Upper or Pennsylvanian development of the Carboniferous is here absent. To the east, the Fernie shales are shown by Leach to be brought against the Devono-Carboniferous by a fault. Mr. Leach's section is reproduced in Plate IV.

The Devono-Carboniferous succession on Turtle mountain is of tolerably uniform character throughout, consisting of heavily bedded bluish-gray limestones alternating with beds which are similar in appearance but which are composed of magnesian limestone. As stated above, the succession here is apparently of Devonian or Lower Carboniferous age and, therefore, too low down in the series to contain beds of phosphate of lime of the age of those found in Montana and the adjacent states.

(c) *The Rocky Mountains Park at Banff, Alberta*: In this section the Carboniferous has an entirely different development from that which it presents on either of the other two lines of section examined and which are described above.

Although more distant from the International boundary than either of the other sections, and no less than 350 miles north of the nearest occur-

*Schofield, S. J.—*The Cranbrook Map Sheet*, Memoir 76, Geological Survey of Canada, 1915

†Daly, R. A.—*The North American Cordillera*, Pt. I, Geological Survey of Canada, 1912, pp. 113 and 117.

††Dowling, D. B.—*The Coal Fields of British Columbia*, Memoir 69, Geological Survey of Canada, 1915, p. 52.



PLATE VI—PHOSPHATE ROCK FOUND IN BED OF FORTY-MILE CREEK, ROCKY MOUNTAINS PARK, BANFF, ALBERTA
Weight 31 lbs.

ence of phosphate in the United States, the Carboniferous section in the Rocky Mountains park at Banff resembles in many respects that which is found in Montana.

The geological succession in the Rocky Mountains park has been mapped and described in detail by Messrs. Dowling and Allan of the Geological Survey of Canada.

Dr. Allan's map and description is to be found in *Guide Book No. 8, Part II*, which was prepared for the transcontinental excursion of the International Geological Congress in 1913, and which was issued by the Geological Survey of Canada. The guide book can be obtained by applying to the Director of the Geological Survey at Ottawa.

The Carboniferous succession according to Dr. Allan is as follows:

CARBON- IFEROUS	PENNSYL- VANIAN	Rocky Mountain Quartzite	800 ft.	White to gray quartzite and arenaceous siliceous limestone.
		Upper Banff limestone	2,300 ft. +	Thick-bedded dark gray limestones with numerous thin cherty layers underlain by thin-bedded limestone and shale; weathering gray.
	MISSISSIPPIAN	Lower Banff shale	1,200 ft.	Black to dark gray shale, argillaceous and calcareous; weathering light brown.
		Lower Banff limestone	1,500 ft. +	Thick-bedded gray limestones with numerous dolomitic segregations.
DEVONIAN		Intermediate limestone	1,800 ft. +	Thin-bedded limestones, with alternating more massive layers of gray dolomitic and siliceous limestone.

This succession, set forth in tabular form in comparison with the carboniferous as developed in Montana and Idaho, is seen on pp. 6 and 7.

As will be noted it presents the fourfold sub-division already noted in the Carboniferous at Maiden Rock, Montana.

In the Georgetown area of Idaho the phosphate beds occur just above the Wells formation which is of Pennsylvanian age (Upper Carboniferous) the overlying rocks consisting of one or more massive strata of cherty limestone or chert. And it is of especial interest to note that near the base of the Wells formation a large variety of *Spirifer rockymontanus* is especially abundant. Allan, in the Guide Book mentioned above, in referring to the Upper Banff limestone of the park, says:

"It is shaly at the bottom, but more massive towards the top. Cherty lenses and cherty shale interbedded with the lower shaly limestone help to

distinguish this formation from the shale below. Fossils, *e.g. Spirifer rocky-montanus*, are quite abundant throughout the lower beds in this series."

VI.—DISCOVERY OF PHOSPHATE ROCK IN THE ROCKY MOUNTAINS PARK AT BANFF

From the presence of the fossil just mentioned and from an examination of the stratigraphical succession as seen in the comparative table on pages 6 and 7, it seemed probable that if the phosphate was present in the Banff area and occurred at the same horizon as in Montana and Idaho, it would be found somewhere near the contact of the Rocky Mountain quartzite and the Upper Banff limestone.

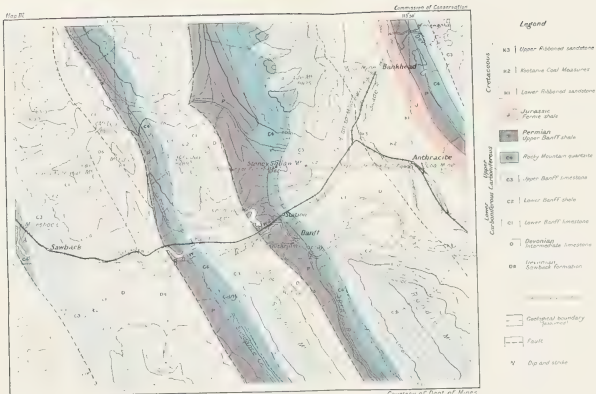
The distribution of these two formations is well shown in the geological map of this area to be found in the Guide Book of the International Geological Congress. This map, with some of the details omitted, is reproduced in Map III. It will be noted on consulting it that the formations are repeated by faulting and appear as sets of parallel bands which cross this area four times in a general north-west and south-east direction.

As will be seen, Forty-mile creek, a small rapid stream which flows into the Bow river near Banff, crosses the Rocky Mountain quartzite and the Upper Banff limestone three times, and a search was accordingly first made among the shingle and blocks of loose rock which are being carried down by this stream for "float" of phosphate rock.

The creek was carefully examined along that portion of its course where it runs between Cascade and Stoney Squaw mountains, and the search was finally rewarded by the discovery of a large mass of compact phosphate rock. This was found by the side of the creek at a point opposite the southeastern end of Stoney Squaw mountain where the pipe line which conveys water from Forty-mile creek to Banff, first approaches close to the creek from the south and where the bank on the opposite side of the creek forms a steep wall coming down to the water's edge. (See Plate I.)

This mass of phosphate "float" was partly rounded and weighed 31 pounds. It measured ten inches by eight inches by six inches, showing that it must have been derived from a bed of some considerable thickness.

It belongs to one of the harder and more compact varieties of the rock which are found in the Montana field and which have been referred to in the description of the phosphate occurrences of that state as somewhat resembling a basalt on the fresh fracture. It is only a hard variety of the phosphate that could survive the violent attrition to which the rock talus is subjected in such a swift and turbulent stream; any of the softer varieties, which may have been associated with it, would have been completely disintegrated and ground to powder by the abrasive action of the swiftly running water. (See Plate VI.)



Banff
Miles

Kilometers

Courtesy of Dept. of Mines

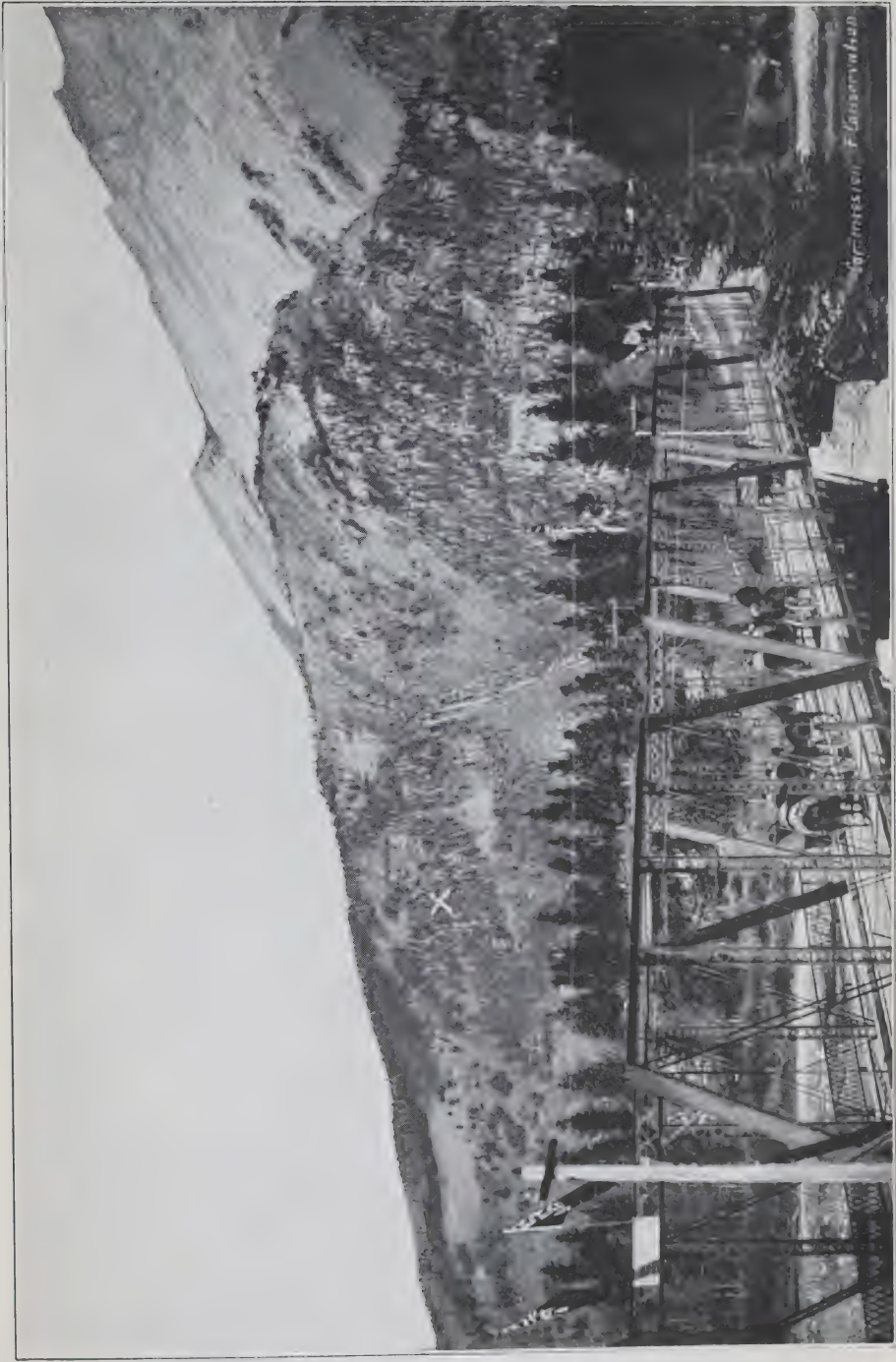


PLATE VII—STONEY SQUAW MOUNTAIN, ROCKY MOUNTAINS PARK, BANFF, ALBERTA
The cross indicates approximately the position where phosphate rock was discovered at contact of Rocky Mountain Quartzite and Upper Banff Limestone.

The phosphate rock found in the bed of Forty-mile creek is very fine grained and massive in character, black in colour and looks like basalt. A careful examination of its broken surface with a good lens shows the oolitic structure—which has been referred to as characterizing this rock—quite distinctly, with the presence of occasional dark rod-like objects described below as seen in the thin sections. In places the rock also shows minute irregular-shaped cavities lined with a coating of some secondary mineral. In these cavities in one or two places little aggregates of minute, transparent, vitreous crystals, colourless to deep purple in colour, were observed. These are in all probability fluorite.

When thin sections of the rock are examined under the microscope, it is seen to be composed of angular and sub-angular grains of clear, colourless quartz embedded in a matrix of phosphate of lime. This matrix is brown in colour and turbid in appearance, being translucent rather than transparent. It is isotropic, showing in some places, however, a very low double refraction. In this phosphate there are distributed here and there irregular shaped, ill-defined darker areas, which apparently owe their deeper colour to the presence of organic matter. The phosphate of lime shows a very striking oölitic or concretionary structure. (See Plate VIII.) This structure, marked by the presence of thin concentric bands alternately lighter and darker in colour, can sometimes be seen as a border about the quartz grains as if the phosphate had been deposited around them. (See Plate VIII, No. 1). But it is seen in the most striking form in the areas of phosphate lying between the grains of quartz. Here the mineral often takes the form of little spheres formed of successive zones varying in depth of colour. These are sometimes, and in fact usually, quite spherical in outline, several of them often occurring together in the space between a number of adjacent grains of quartz, the interval between the spheres being occupied by structureless phosphate. Occasionally, however, instead of spherical forms, elongated outlines, like those which would be produced by cutting short stout rods or cylinders, are seen. These show circular or elliptical cross sections, suggesting that many of the apparently spherical concretions may really be transverse sections of these rods. As a matter of fact, however, both are present. (See Plate VIII, No. 2.)

In some few cases also, forms resembling sections through minute fragments of ostracod shells and other organic forms are seen. (See Plate IX, No. 1.)

In some of the thin sections a few of these rounded, elliptical and rod-like forms are seen to be composed of, or filled with, an isotropic mineral of a deep purple colour, the colour being so intense in most cases that the mineral is nearly opaque. This mineral also occurs disseminated in the phosphate. It resembles fluorite in colour but its opacity suggests a doubt as to whether it is really referable to this species. The rounded black

forms shown in the microphotograph on Plate IX. No. 2 are composed of this mineral. An occasional grain of brown tourmaline and of zircon (?) is also seen in the thin sections.

A specimen of this phosphate rock was, at the direction of the Deputy Minister of Mines, analyzed by Mr. M. F. Connor, of the Department of Mines. It was found to have the following composition:

Lime.....	33.70	per cent
Phosphoric Acid (P_2O_5).....	24.71	" "
Silica.....	38.41	" "
Ferric Oxide and Alumina.....	.57	" "
Magnesia.....	.21	" "
Manganous Oxide.....	trace	
Fluorine.....	1.50	" "
Alkalies.....	.40	" "
Water and Organic Matter.....	1.10	" "
	100.60	" "
Less Oxygen.....	.63	" "
Total.....	99.97	" "

There is present Phosphate of Lime ($3 \text{ CaO}, P_2O_5$) = 53.95 per cent.

The discovery of the phosphate rock as "float" in Forty-mile creek has demonstrated that deposits of this rock must exist somewhere along the course of this stream. Time did not, however, permit of a careful examination of the several belts of strata which have been mentioned above as those in which the phosphate rock was most likely to occur, and which repeatedly cross the creek. A search was made, however, on Stoney Squaw mountain, which is crossed by the contact of the Rocky Mountain quartzite and the Upper Banff limestone, and which thus seemed to present a probable locality for the occurrence of phosphate. This mountain, having a height of 6,160 feet, lies immediately to the south of Cascade mountain, which rises to an elevation of 9,825 feet. The narrow valley between is occupied by Forty-mile creek, which flows into the Bow river near Banff. On Dr. Allan's map, to which reference has been made, the geology of Stoney Squaw mountain is not shown quite accurately, for the contact of the Rocky Mountain quartzite with the Upper Banff limestone, instead of crossing near the foot of the mountain on the eastern side, really passes over the western slope, the mountain being thus composed almost entirely of the Upper Banff Limestone formation.

The Upper Banff limestone here consists of beds of pure limestone interstratified with beds of highly magnesian limestone, the whole dipping to the west. The limestones, and especially the magnesian limestones, often contain much chert in the form of nodules and irregular masses, while heavy beds of chert mark the contact of this formation with the overlying Rocky Mountain quartzite.

At one point on the southern slope of the mountain, in a depression which marks the contact of the Rocky Mountain quartzite and the Upper Banff limestone (See Plate VII), a loose angular mass of quartzite, evidently derived from the underlying strata, was found, which on examination was seen to contain a considerable percentage of phosphate of lime. While not itself sufficiently rich in phosphoric acid to be exploited for that material, its discovery at this, which is the exact horizon in which, as has been indicated, phosphate rock might be expected to occur, serves to stimulate search along this line of contact for other larger and richer bodies of this valuable material.

This rock in which phosphate was found is a quartzite, fine grained and dark gray in colour, the phosphatic portions not being readily distinguished from the normal rock.

Under the microscope it is seen to be composed of angular, semi-angular and rounded grains of quartz with a small amount of feldspar and a little dark organic matter between the grains. A few minute grains of monazite or zircon, with high index of refraction and high double refraction, but without good crystallographic form—such as are so frequently seen in sandstones derived from the disintegration of granitic rocks—are also present.

The phosphate is dark in colour, isotropic and in those portions of the rock where it is present lies between the quartz grains, embedding them and cementing them together. It shows the same oolitic structure as is seen in phosphate rock found in Forty-mile creek, but this structure is usually not developed in such a striking manner.

A chemical examination of this rock shows the content of phosphoric acid to be as follows: Phosphoric Acid (P_2O_5) . . . 7.6 per cent. This is equivalent to a content of 16.6 per cent of tricalcium phosphate.

A significant fact in this connection is that while specimens of the magnesian limestones of the Upper Banff limestones have been found to be free from phosphoric acid, the cherts which occur in the formation and along its contact with the overlying Rocky Mountain quartzite uniformly contain small amounts of this acid. Having found this to be true from qualitative tests made on these cherts, four typical specimens of chert from different parts of Stoney Squaw mountain were collected and the amount

of phosphoric acid which they contained was determined quantitatively in the Laboratory of the Department of Mines, with the following result:

Phosphoric acid, P_2O_5 —No. 1.....	.15 per cent.
“ “ “ —No. 2.....	.10 “ “
“ “ “ —No. 3.....	.06 “ “
“ “ “ —No. 4.....	.30 “ “

The almost invariable presence of chert in association with the phosphate beds in the Western States, which has previously been mentioned, and the presence of phosphoric acid in the chert of this Banff district, suggests that there is some genetic connection between the chert and the phosphate rock and that the presence of phosphoric-acid bearing cherts may be an indication of the proximity of phosphate deposits.

VII.—SUGGESTIONS FOR PROSPECTORS IN SEARCH OF DEPOSITS OF PHOSPHATE ROCK IN THE ROCKY MOUNTAINS

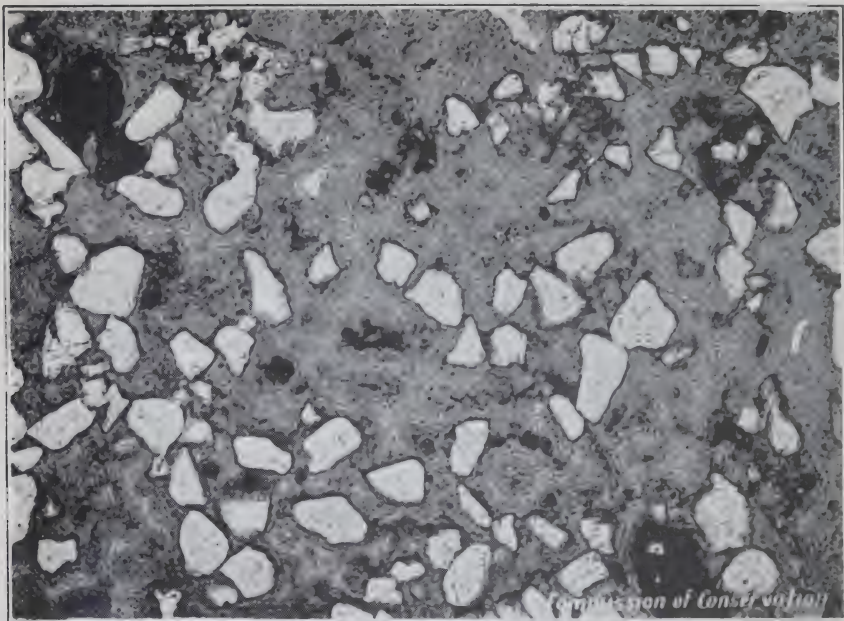
1. As has been already stated this phosphate rock may be expected to occur at a certain definite geological horizon near the top of the Carboniferous system. In prospecting for phosphate in the Rocky mountains, therefore, the search should be confined more particularly to rocks of this horizon.

In the central portion of the Rocky Mountains park the formations in which phosphate is most likely to be found are easily recognized and are shown on Dr. Allan's map and on the map accompanying this paper.

2. These formations, however, continue along their strike beyond the limits of the park both to the south and in a northerly direction. The probable phosphate horizon can, therefore, be followed in these directions. An extended report on the geology of the Rocky mountains by Dr. Allan will be issued shortly by the Geological Survey of Canada, and in this, more information on the geology of this region will be given than is available at the present time.

3. One of the chief difficulties which presents itself in prospecting for phosphate rock in the Rocky Mountain region of Canada is that of recognizing this rock when it is found. It bears a close resemblance in appearance to the limestones and magnesian limestones as well as to certain of the cherts which are found abundantly in strata of Upper Carboniferous age. The prospector should provide himself with an acid bottle of large size and employ it freely. An excellent acid bottle for this purpose may be obtained by securing one of the larger sized bottles in which ink for safety pens is sold. These are provided with a rubber cork pierced by a glass tube drawn out to a narrow opening at one end and having a collapsible rubber bag at the other. The whole is enclosed in a light turned wooden case with

No. 1



No. 2

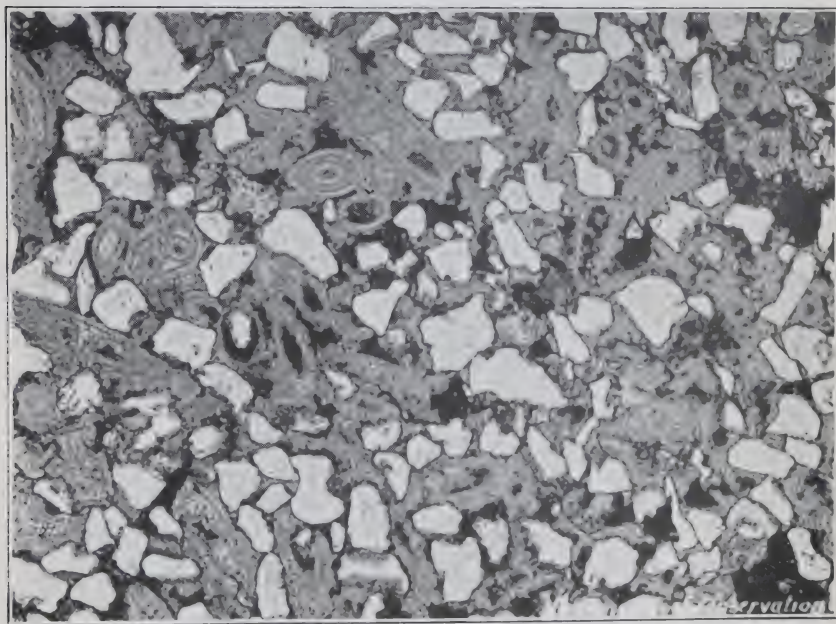


PLATE VIII—MICROPHOTOGRAPHS OF PHOSPHATE ROCK, FORTY-MILE CREEK,
ROCKY MOUNTAINS PARK, BANFF, ALBERTA
Magnified 56 diameters

a top that screws on. The ink should be poured out and the bottle washed and filled with hydrochloric acid diluted with an equal volume of water.

In examining any specimen of dark rock which resembles phosphate rock a few drops of this dilute acid should first be dropped upon it. If an effervescence results, the rock is a limestone. If not, the specimen should be pounded with the hammer to bruise it and the powder so produced should be treated with the acid. If it now effervesces, it is a magnesian limestone. If, however, it still shows no effervescence, an attempt should be made to scratch it with the hammer or by means of a knife. If a narrow line having a bright shining metallic appearance is traced upon the surface of the rock, it is harder than the steel and is a chert or fine-grained quartzite.

When the possibility of the specimen belonging to one or other of these several classes of rock has been eliminated, it should be carefully examined with a lens when, if it be phosphate rock, it will probably show a surface studded with minute spheres, black in colour, or little circles representing these spheres in cross section. This is the oolitic structure referred to in the description of this rock. The rock, if massive, will also be distinctly heavier than the common rocks of the region. Sometimes upon breaking it a fetid odour can be noticed.

4. In order, however, to be certain that the specimen in question contains phosphoric acid, it is necessary to submit it to a chemical test. This may be done in the following manner:

Powder some chips of the rock in a mortar until the material will pass through a 100 mesh sieve. Place as much of the powder as can be taken up readily on a twenty-five cent piece in an ordinary small enamel cup, add about 30 cc. of water and 10 cc. of concentrated nitric acid. Cover the cup with a large watch glass and warm gently for ten minutes. Filter, or decant off the fluid if it is clear, into a glass beaker and add 100 cc. of water, then a few cubic centimetres of a saturated solution of carbonate of ammonia. This will probably make the clear solution somewhat cloudy. Nitric acid should then be added drop by drop until the solution clears up again and gives a faint but distinct acid reaction with blue litmus paper. The solution is then warmed again to a temperature of 70° or 80° C. and 50 cc. of a concentrated solution of molybdate of ammonia is added drop by drop, while the solution is being stirred. This solution is allowed to stand in a warm place for 15 minutes; if phosphoric acid is present, a bright yellow granular precipitate of phospho-molybdate of ammonia will appear.

5. If it is desired to determine in the field approximately the percentage of phosphoric acid present in the rock, the following method, which is essentially that used by the United States Bureau of Soils in the examination of the phosphate beds of the Western United States, may be employed:

The sample is crushed in an iron mortar, pulverized in a small porcelain mortar, and finally put through a 100 mesh screen. Two grams of the powder are weighed and brushed into an enamel cup; 25 to 30 cc. of water are added and then 10 cc. of concentrated nitric acid. The cup is covered with a watch glass, placed on an iron plate over a coal oil burner, and the contents allowed to digest for seven or eight minutes. After cooling somewhat, the insoluble material is filtered off, washed thoroughly on the filter, and the filtrate made up to 200 cc. with water. This solution is thoroughly mixed and 20 cc. of it is then taken for analysis. This is diluted with 30 cc. of water and a few cubic centimetres of a saturated solution of ammonium carbonate added. Sufficient nitric acid to dissolve any precipitate and render the solution acid to litmus paper is then added. The beaker is then placed on the hot plate, heated to 70° or 80° C. and 100 cc. of a concentrated solution of ammonium molybdate is added, drop by drop, with constant stirring. After standing ten minutes the solution above the precipitate of ammonium phospho-molybdate is decanted off and filtered, and the precipitate washed as far as possible by decantation until the washings give no acid reaction. The filter and its contents are then returned to the beaker, a little water added, and a standard solution of potassium hydroxide run in from a burette until the yellow precipitate dissolves. A few drops of phenolphthalein are added and standard nitric acid (matched against the potash solution) is run in from a burette, drop by drop, until the pink colour of the indicator—phenolphthalein—disappears. The quantity of nitric acid used, subtracted from the amount of potassium hydroxide, gives the number of cubic centimetres of the latter solution required to dissolve the yellow precipitate. The potassium hydroxide employed should be of such strength that one cc. equals one milligram of phosphoric acid.

In order to be certain that all the phosphoric acid has been precipitated, it is well to add another 25 cc. of the ammonium molybdate solution to the clear filtrate from the yellow precipitate and allow the beaker to stand on the warm plate for another half hour.

The standard solution of potassium hydroxide, as well as the standard nitric acid, should be carefully prepared in a laboratory and taken into the field in stout stoppered glass bottles.

The following method for the accurate determination of phosphoric acid if laboratory facilities are available is recommended by the Committee on Research and Analytical methods, Division of Fertilizer Chemists, American Chemical Society:*

"To 5 grams of the sample add 30 cc. of concentrated hydrochloric acid (sp. gr. 1.20) and 10 cc. of concentrated nitric acid (sp. gr. 1.42) and boil down to a syrupy consistency. The residue, which should be nearly solid

**The American Fertilizer*, July 24th, 1915, p. 60.



PLATE IX—MICROPHOTOGRAPHS OF PHOSPHATE ROCK, FORTY-MILE CREEK, ROCKY MOUNTAINS PARK, BANFF, ALBERTA
Magnified 56 diameters.

after cooling, is taken up with 5 cc. of concentrated nitric acid and 50 cc. of water. Heat to boiling, cool, filter and make up to 500 cc. through the filter. This procedure eliminates practically all of the silica, and it is necessary to filter as quickly as possible after digestion so as to avoid re-dissolving the silica.

"Draw off an aliquot portion of 50 cc. corresponding to 0.5 gram, neutralize with ammonia and just clear with nitric acid. Add 15 grams of ammonium nitrate (free from phosphates), heat the solution to 50° C. and add 150 cc. of molybdate solution. Digest at 50° C. for fifteen minutes with frequent stirring. Filter off the supernatant liquid and test the filtrate with molybdate solution to see if precipitation has been complete. (If not, add more molybdate to the filtrate and digest for fifteen minutes longer.) Wash with five per cent ammonium nitrate solution by decantation, retaining as much of the precipitate as possible in the beaker. Dissolve the precipitate in the beaker in the least possible quantity of ammonium hydroxide (sp. gr. 0.90) and dilute this solution with several times its volume of hot water. Dissolve the remainder of the precipitate on the filter with this solution, washing beaker and filter with hot water and keeping the volume of the filtrate between 75 cc. and 100 cc. Neutralize with hydrochloric acid, cool to room temperature and add 25 cc. of magnesia mixture from a burette, drop by drop, stirring vigorously with a rubber-tipped rod, then add 15 cc. of ammonium hydroxide (sp. gr. 0.90) and allow to stand for four hours, or over night, at room temperature. The time of standing may be reduced to two hours if kept in a refrigerator or, still better, in an ice water bath. Filter through a platinum or porcelain Gooch crucible, fitted with a carefully made asbestos or platinum mat and ignited to constant weight. Wash with 2.5 per cent ammonium hydroxide until practically free from chlorides, dry, ignite, cool and weigh as magnesium pyrophosphate. If desired, filtration may be made through an ashless filter paper, igniting in the usual manner. Calculate to P_2O_5 by multiplying by 0.6378 (log 80468)."

VIII.—DOMINION REGULATIONS RESPECTING DISPOSAL OF PHOSPHATE LANDS

Mineral deposits on Dominion lands in the provinces of Manitoba, Saskatchewan, Alberta, North-west Territories and Yukon are disposed of under *Regulations for the Disposal of Quartz Mining Claims**.

These regulations state that : "Minerals shall mean all valuable deposits of gold, silver.....phosphorus.....etc."

From the above it can be seen that the disposal of phosphate deposits in these provinces comes under the Quartz Mining Regulations. An amendment† to the Dominion Lands Act provides that Dominion lands shall not be sold and no Crown grants will be issued for mineral claims, staked under Quartz Mining Regulations, after the date the amendment came

*Approved by Order-in-Council, August 13, 1908 and amended by subsequent Orders-in-Council.

†4-5 George V, chap. 27, assented to, June 12th, 1914.

into force; leases of occupation will probably be issued in lieu thereof, but as no one has earned a Crown grant since the above date, this method of disposal has not yet been determined.

The size of a claim located under these regulations is 1,500 feet by 1,500 feet and no person is entitled to hold in his own name or in the name of any other person more than one claim on the same vein or lode, or within a distance of one-half mile, except by purchase, but such person may hold by location a claim upon any separate vein or lode.

Should the phosphate deposits in the Rocky mountains prove to occur in extent and quantity comparable with those in the Western States it would be necessary for the Dominion Government to make new regulations dealing with the working of phosphate lands within this area.

Appendix

PHOSPHATE RESOURCES OF THE WORLD

TABLE I.—Phosphate production of the world from 1908 to 1913, in tons of 2,000 pounds.

COUNTRY	1908	1909	1910	1911	1912	1913
Algeria.....	497,200	386,200	453,200	351,000	427,300	507,100
Angaur Palan Iseln.....		9,900	49,500	45,100	55,000	
Australia.....			5,700	6,500		
Belgium.....	217,800	225,500	223,000	216,400		(a) 195,800
Canada.....	1,596	998	1,478	621	164	385
Christmas Island.....	286,000	217,800	341,600	275,000	330,000	165,000
Dutch West Indies						
Aruba.....	22,000	29,700	29,800	(a) 29,700		
Curacao.....			3,800	(a) 1,900		
Egypt.....	800	1,100	2,600	7,000	77,000	70,000
France.....	533,600	437,800	366,400	343,200		
French Guiana.....	9,900	9,900	7,400			
Makatea.....				13,200	44,000	
Norway.....	1,940	1,450	1,000			
Ocean and Naurn Islands	330,000	217,800	341,000	275,000	330,000	
Russia.....	16,200	14,200	16,800	11,000		
Spain.....	4,900	1,500	3,100	3,900		
Sweden.....					3,600	
Tunis.....	1,430,000	1,345,300	1,414,800	1,591,200	2,115,300	1,983,300
United States.....	2,654,300	2,753,400	2,997,200	3,586,000	3,537,600	3,374,800
Totals.....	6,006,236	5,652,548	6,258,378	6,756,721	6,919,964	6,296,385

(a) Exports

TABLE II.—Imports of phosphate into the principal countries of the world from 1911-1913, in tons of 2,000 pounds.

COUNTRY	1911	1912	1913
England (a).....	.....	567,600	602,400
France.....	814,300	993,800	1,028,000
Germany (b).....	916,600	993,100	883,300
Japan (c).....	.....	.....	.....
Russia (d).....	364,900	378,800	.....
Spain.....	.....	477,700	506,400

(a) Includes basic slag and guano.

(b) In 1913 over 50 per cent of German imports of phosphate came from the United States.

(c) Statistics not available, but it is known that besides a large tonnage imported from Algeria, Tunis and the islands of the Pacific, Japan imports 90 per cent of the output of Egypt.

(d) Includes all fertilizers containing phosphate.

United States: The United States is not only the largest producer of phosphate rock but has a known reserve far greater than any other country.

Owing to the irregular character of some of the American deposits accurate estimates can be made only after careful work. The following estimates are from data collected by the United States Department of Agriculture. The figures represent rock grading from 60 to 70 per cent bone phosphate of lime. In the case of the low-grade phosphate in the West and the wash heaps of Florida, the material is figured to its equivalent in high-grade rock.

TABLE III.—Reserve supply of phosphate rock in United States.

<i>Utah, Idaho, Wyoming and Montana:</i>	Tons
High-grade.....	2,500,000,000
High-grade equivalent of all grades.....	7,500,000,000
<i>Florida:</i>	
High-grade.....	354,300,000
High-grade equivalent of wash heaps.....	20,000,000
<i>Tennessee:</i>	
High-grade equivalent of all grades.....	115,075,000
<i>South Carolina:</i>	
High-grade equivalent of all grades.....	10,000,000

Arkansas:

High-grade equivalent of all grades.....	20,000,000
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Kentucky:

High-grade equivalent of all grades.....	500,000
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Total.....	10,519,875,000
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The phosphate deposits of the United States are distributed principally among four localities: (1) Along the west coast of Florida; (2) along the coast of South Carolina; (3) in central Tennessee; and (4) in an area comprising south-eastern Idaho, south-western Wyoming, north-eastern Utah and in west-central Montana. In addition to these areas some deposits occur in Arkansas, North Carolina, Alabama and Mississippi.

The production of Tennessee is increasing, that of Florida appears to have reached its maximum, the South Carolina output is diminishing, and the Arkansas deposits are of low grade. For these reasons the largest future production must come from the western deposits.

At the Conference of Governors in 1908 attention was directed to the possibility of foreign investors acquiring the better known and supposedly richer portions of phosphate deposits in the United States*; also the question of the future adequacy of the phosphate resources for the needs of that nation had previously been mentioned by several authorities. Partly on this account the Secretary of the Interior, in 1908 withdrew from entry about 7,000 square miles of public land in Idaho, Utah, and Wyoming, pending an examination of their phosphate resources. Since that time the United States Geological Survey has examined in a preliminary way some 4,000 square miles and surveyed in detail some 2,500 square miles.

Africa: The phosphates of Northern Africa including those of Tunis, Algeria and Egypt, are next in importance to those of the United States. The total output in 1913 was 2,328,800 tons.

The phosphate deposits of Tunis and Algeria occur in large lenses of considerable thickness and range in grade from 58 to 68 per cent bone phosphate of lime.

The Egyptian deposits have been found in various portions of the desert regions and in the valley of the Nile. They occur in rocks of Cretaceous age. The rock grades from 30 to 68 per cent bone phosphate of lime.

Islands of the Pacific and Indian Oceans: The highest grade deposits of amorphous phosphate yet discovered are those of the Pacific and Indian oceans. Among the more important phosphate-producing islands are Ocean island (British), Tahiti and Makatea (French) and the island of

*See *Classification of Public Lands*, United States Geological Survey, Bull. 537, page 127.

Naru (German). Besides these, Christmas island in the Indian ocean contains a large tonnage of high grade rock.

The phosphates are derived from bird excrements which have been leached and their phosphoric acid fixed by the underlying coral rock; much of the material contains as high as 87 per cent bone phosphate of lime.

Russia: Phosphorites occur over a large area in Russia, but the southern region near the Austrian frontier is the only one that has been exploited. The deposits occur in Jurassic and Cretaceous rocks and the average grade of the rock is about 75 per cent bone phosphate of lime. Much of the material is shipped to Poland and made into acid phosphate; fertilizers are also imported to Russia in large quantities from Germany, Belgium and England.

France and Belgium: The phosphates of France and Belgium occur both in Tertiary and Cretaceous rocks with an average content of phosphate of lime of about 50 to 55 per cent. On account of the discovery of higher grade rock in other portions of the world phosphate mining has fallen off, although large quantities of raw material are imported and manufactured into soluble phosphates.

Germany: Germany has no phosphate deposits of commercial value, but imports a very large tonnage from the United States, Tunis, Algeria and Belgium. The imports in 1912 amounted to about 1,000,000 tons valued at \$10,743,800. Practically all of the rock is made into acid phosphate for domestic consumption.

England: Phosphate has not been found in sufficient quantities in the British Isles to prove of commercial importance.

Peru: The Peruvian guano deposits have been, and are, important sources of phosphoric acid and nitrogen.

Canada: With regard to the phosphate industry in Canada, Mr. McLeish in the Annual Report of the Mines Branch, Department of Mines for 1913, on *Mineral Production of Canada* states:

"The small production of phosphate or apatite, which has been obtained in Canada since 1896, has been produced almost altogether as a by-product in connection with the mining of mica. Shipments during 1913 were 385 tons, valued at \$3,643, shipped chiefly from the Little Rapids mine, township of Portland East, with a small quantity from Davidson Corners, Que.

"Phosphate is used at Buckingham, Que., in the manufacture of ferro-phosphorus, phosphorus, and fertilizers, and the main supply is now imported from Florida.

"For a number of years previous to 1892, there was a considerable production of apatite from the district north of Buckingham, the annual output varying from 20,000 tons to 30,000 tons. The introduction of the cheaply-mined phosphates of the Southern States, however, resulted in the collapse of the Canadian industry, though it was claimed at the time of closing down that there was no diminution in the available supply of mineral.

"Statistics of production and exports are shown in the tables following:

TABLE IV.—ANNUAL PRODUCTION OF PHOSPHATE IN CANADA

Calendar Year	Tons	Value	Average value per ton	Calendar Year	Tons	Value	Average value per ton
		\$	\$ cts.			\$	\$ cts.
1886.....	20,495	304,338	14. 85	1900.....	1,415	7,105	5.02
1887.....	23,690	319,815	13. 50	1901.....	1,033	6,280	6.07
1888.....	22,485	242,285	10. 77	1902.....	856	4,953	5.79
1889.....	30,988	316,662	10. 21	1903.....	1,329	8,214	6.18
1890.....	31,753	361,045	11. 37	1904.....	817	4,590	5.62
1891.....	23,588	241,603	10. 24	1905.....	1,300	8,425	6.48
1892.....	11,932	157,424	13. 20	1906.....	850	6,375	7.50
1893.....	8,198	70,942	8. 65	1907.....	824	6,018	7.30
1894.....	6,861	41,166	6. 00	1908.....	1,596	14,794	9.26
1895.....	1,822	9,565	5.25	1909.....	998	8,054	8.07
1896.....	570	3,420	6. 00	1910.....	1,478	12,578	8.51
1897.....	908	3,984	4.39	1911.....	621	5,206	8.38
1898.....	733	3,665	5.00	1912.....	164	1,640	10.00
1899.....	3,000	18,000	6. 00	1913.....	385	3,643	9.46

TABLE V.—EXPORTS OF PHOSPHATE FROM CANADA

Calendar Year	ONTARIO		QUEBEC		TOTAL	
	Tons	*Value	Tons	*Value	Tons	*Value
		\$		\$		\$
1878.....	824	12,278	9,919	195,831	10,743	208,109
1879.....	1,842	20,565	6,604	101,470	8,446	122,035
1880.....	1,387	14,422	11,673	175,664	13,060	190,086
1881.....	2,471	36,117	9,497	182,339	11,968	218,456
1882.....	568	6,338	16,585	302,019	17,153	308,357
1883.....	50	500	19,666	427,168	19,716	427,668
1884.....	763	8,890	20,946	415,350	21,709	424,240
1885.....	434	5,962	28,535	490,331	28,969	496,293
1886.....	644	5,816	19,796	337,191	20,440	343,007
1887.....	705	8,277	22,447	424,940	23,152	433,217
1888.....	2,643	30,247	16,133	268,362	18,776	298,609
1889.....	3,547	38,833	26,440	355,935	29,987	394,768
1890.....	1,866	21,329	26,591	478,040	28,457	499,369
1891.....	1,551	16,646	15,720	368,015	17,271	384,661
1892.....	1,501	12,544	9,981	141,221	11,482	153,765
1893.....	1,990	11,550	5,748	56,402	7,738	67,952
1894.....	1,980	10,560	3,470	29,610	5,450	40,170
1895.....	.....	.....	250	2,500	250	2,500
1896.....	1	5	299	2,990	300	2,995
1897.....	70	450	165	400	235	850
1898.....	21	240	702	8,000	723	8,240
1899.....	215	1,850	93	1,725	308	3,575
1900.....	.....	.....	.....	.....	.....	.....
1901.....	.....	.....	.....	.....	6	120
1902.....	.....	.....	.....	.....	70	1,880
1903.....	.....	.....	.....	.....	1	20
1904.....	.....	.....	.....	.....	191	5,348
1905.....	.....	.....	.....	.....	40	1,253
1906.....	.....	.....	.....	.....	.....	.....
1907.....	.....	.....	.....	.....	.....	.....
1908.....	.....	.....	.....	.....	1	30
1909.....	.....	.....	.....	.....	895	15,735
1910.....	.....	.....	.....	.....	.....	.....
1911.....	.....	.....	.....	.....	3	100
1912.....	.....	.....	.....	.....	.....	.....
1913.....	.....	.....	.....	.....	.....	.....

*These values do not compare with those in Table 1; the spot value is adopted for the production, while the exports are valued upon quite a different basis.

"The imports of phosphate rock (fertilizer) for 1913 were valued at \$16,070; phosphorus 17,600 pounds, valued at \$5,856; and manufactured fertilizers, valued at \$505,904. The imports in 1912 included phosphate rock (fertilizer), valued at \$24,586; phosphorus 13,807 pounds, valued at \$4,012; and manufactured fertilizers, valued at \$580,351.

"Phosphorus is manufactured at Buckingham (Quebec) by the Electric Reduction Company. The exports of phosphorus during the twelve months ending December 31, 1913, were 534,340 pounds, valued at \$73,395, as compared with 543,620 pounds, valued at \$66,806 in 1912, and 524,370 pounds, valued at \$76,608 in 1911."

Other Countries: Deposits of phosphate have been discovered on Rasa island at the extreme end of the Loochoo islands. The material averages about 77 per cent bone phosphate and the island is estimated to contain 2,800,000 tons, but it has not been developed to any great extent. Phosphate occurs on the Pratas islands 170 miles south of Hong Kong, China. The quantity of phosphate contained in these deposits is estimated at 960,000 tons. High grade phosphate is also found on the island of Curaçao, one of the Dutch West Indies.

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INDEX

	PAGE
Africa, phosphate resources of.....	27
Alabama, occurrence of phosphate in.....	27
Alberta—	
occurrence of Carboniferous rocks in.....	2
soil depletion in.....	4
Algeria, phosphate deposits in.....	27
"Algonkian" formation.....	12
Alkalies, percentage in phosphate rock of.....	18
Allan, Dr.....	15, 18, 20
Altyn limestone.....	12
Alumina, percentage in phosphate rock.....	18
American Chemical Society, method of analysis recommended by.....	22
Anaconda Copper and Mining Co.....	5, 9
Analysis of phosphate rock, methods of.....	21, 22
Apatite.....	1, 28
Appekunny formation.....	12
Arkansas, phosphate resources of.....	27
Banff, Alberta.....	10, 14, 16
Bankhead, Alberta, geological section near.....	7
Basalt, resemblance of phosphate to.....	9, 17
Belgium, phosphate resources of.....	28
Bone phosphate of lime.....	27, 28, 31
Bonnie, C. A.....	5
Bow river.....	16
Brachiopod fauna, near North Kootenay pass.....	13
British Columbia, occurrence of Carboniferous rocks in.....	2
Buckingham, Que.....	28
Burling, Mr.....	13
Butte City, Montana.....	5
Cambrian.....	12, 13
Canada—	
annual phosphate production in.....	29
exports and imports of phosphate in.....	30
phosphate industry in.....	28
wheat production in.....	3
Carboniferous system.....	4, 5, 7, 8, 12, 15
phosphate horizon in.....	1, 4, 20
Cascade mountain.....	16
Chert, analysis of.....	20
Christmas island, occurrence of phosphate in.....	28
Clarke range, structural section of.....	11
Commission of Conservation, agricultural investigations by.....	4
Connor, M. F., analysis of phosphate rock by.....	18
Cretaceous.....	5, 6, 7, 8, 12
Crowsnest pass.....	14
Curaçao, occurrence of phosphate in.....	31

	PAGE
Daly, R. A.....	11, 14
Davidson Corners, Que., phosphate from.....	28
Dawson, Dr. G. M.....	10, 11, 12, 13
Devonian.....	12, 15
Devono-Carboniferous.....	6, 14
Dowling, D. B.....	14
Egypt, phosphate deposits in.....	27
Electric Reduction Co.....	30
Ellis formation.....	5, 8
Elliston, Montana, geological section at.....	6
England, absence of phosphate deposits in.....	28
Feldspar.....	19
Fernie shales.....	14
Ferric oxide, percentage in phosphate rock.....	18
Fertilizers, increasing demand for.....	1
Flathead valley.....	10, 13
Florida, phosphate resources of.....	26
Fluorine, percentage in phosphate rock of.....	18
Fluorite in phosphate rock.....	17
Forty-mile creek, discovery of phosphate in.....	16, 18, 19
France, phosphate resources of.....	28
Frank, Alberta, geological section near.....	6
Georgetown area, Idaho.....	15
Germany, importation of phosphate into.....	28
Governors, Conference of.....	1, 27
Grinnell formation.....	12
Guano deposits in Peru.....	28
Helena, Montana.....	10
Hill, James J.....	2
Hopkins, Dr. C. G.....	3
Idaho—deposits of phosphate in.....	1, 4
phosphate resources of.....	25
section of phosphate area in.....	7
Illinois, decrease of yields of wheat in.....	2
Indiana, decrease of yields of wheat in.....	2, 3
International Geological Congress, guide book of.....	16
Iowa, decrease of yields of wheat in.....	2
Jurassic formation.....	5, 6, 7, 8
Kentucky, phosphate resources of.....	27
Kindle, Dr. R. C.....	13
Kintla argillite.....	12
Kootenai formation.....	5, 6, 8
Leach, Mr.....	14
Lewis overthrust fault.....	10
Lewis range.....	11
Lime, percentage in phosphate rock.....	18
Lindforth, Dr.....	5
Little Rapids mine.....	28
Livingston range.....	11
Loochoo islands, occurrence of phosphate in.....	31

	PAGE
Madison limestone.....	7, 8
Magnesia, percentage in phosphate rock of.....	18
Maiden Rock, Montana.....	5, 8, 9, 15
Makatea, occurrence of phosphate in.....	27
Manganous oxide, percentage in phosphate rock of.....	18
Manitoba, depletion of soil in.....	4
McLeish, Mr.....	28
Melrose, Montana, geological section at.....	6
Mesozoic formations.....	6
Mining regulations on Dominion lands.....	23
Mines, Department of.....	18, 20, 28
Minnesota, yields of wheat in.....	3
Mississippi, occurrence of phosphate in.....	27
Mississippian formation.....	6, 7, 8, 13, 14, 15
Monazite in phosphate rock.....	19
Montana—	
deposits of phosphate in.....	1, 4
phosphate resources of.....	26
Naru, occurrence of phosphate in.....	28
New York state—	
continuous cropping in.....	2
yields of wheat in.....	3
Nitrogen, sources of.....	3
North Carolina, occurrence of phosphate in.....	27
North Dakota, yields of wheat in.....	3
North Kootenay pass.....	10, 13
Ocean island, occurrence of phosphate in.....	27
Ohio, decrease of yield of wheat in.....	2
Oklahoma, decrease of yield of wheat in.....	3
Oolitic structure in phosphate rock.....	9, 17
Ostracod shells in phosphate rock.....	17
Ottawa district, deposits of apatite in.....	1
Phosphate—	
exports and imports in Canada of.....	30
imports into principal countries of.....	26
Phosphate deposits, leading references to.....	31
Phosphate of lime, discovery in Canada of.....	2, 16
Phosphate production of the world.....	25
Phosphate rock—	
amount to offset soil depletion in Prairie provinces.....	4
chemical composition of sample of.....	18
how recognised.....	20
quantitative field analysis of.....	21
structure of.....	9, 17, 19
Phosphoria series.....	5
Phosphoric acid—	
accurate determination of.....	22
chemical tests for.....	21
importance as fertilizer.....	1, 4
percentage in various phosphate rocks.....	9, 18, 19, 20

Phosphoric acid (<i>continued</i>)—	PAGE
quantitative field determination of	21
Phosphorus—	
importance as constituent of fertilizers	3
manufacture in Canada of	30
Pennsylvanian formation	5, 6, 7, 8, 15
Permian formation	6, 7
Permo-Triassic formation	12
Peru, guano deposits in	28
Potash, importance as fertilizer	3
Prairie provinces, depletion of soil in	4
Pratas islands, occurrence of phosphate in	31
Pre-Cambrian	13
Quadrant formation	6, 8
Quartz mining regulations	23
Rasa island	30
"Red Beds"	11, 13
Rocky mountains, geological examination of	2
Rocky Mountains park	10, 14, 20
Rocky Mountain quartzite	15, 16, 18, 19
Russia, phosphate resources of	28
Saskatchewan, soil depletion in	4
Schofield, S. J.	13, 14
Shepherd quartzite	12
Silica, percentage in phosphate rock	18
Siyeh limestone	12, 13
Soils, method of analysis by United States Bureau of	21
South Carolina, phosphate resources of	26, 27
<i>Spirifer rockymonianus</i>	15, 16
Stoney Squaw mountain	16, 18, 19
Summit mountain	13
Tahiti, occurrence of phosphate in	27
Tennessee, phosphate resources of	26
Tourmaline, occurrence in phosphate rock of	18
Triassic formation	6, 7, 12
Tricalcium phosphate	9, 19
Trilobite fauna near North Kootenay pass	13
Tunis, phosphate deposits in	27
Turtle mountain, Alberta, section examined at	10, 14
United States—	
distribution of phosphate deposits in	27
phosphate resources of	26
United States Geological Survey	1, 27
Upper Banff limestone	15, 16, 18, 19
Utah, phosphate resources of	1, 4, 26
Wardner formation	14
Wasatch limestone	8
Wells formation	15
Willis, Bailey	11, 12
Wyoming, phosphate resources of	1, 4, 26
Zircon in phosphate rock	18, 19

